The Dissertation Committee for Kenneth Martin Brown Certifies that this is the approved version of the following dissertation:

The Bench Deposits at Berger Bluff: Early Holocene-Late Pleistocene Depositional and Climatic History

Committee:

Thomas R. Hester, Supervisor

Samuel M. Wilson, Co-Supervisor

Michael R. Bever

Michael B. Collins

Darrell G. Creel

Ernest L. Lundelius, Jr.

The Bench Deposits at Berger Bluff: Early Holocene-Late Pleistocene Depositional and Climatic History

by

Kenneth Martin Brown, B.A., M.A.

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Dedication

This dissertation is dedicated to two of my first archeology teachers, Cecil A. Calhoun (1932-2003) and Dee Ann Story. Both of them exemplify the value of pursuing inquiry with careful attention to detail.

Acknowledgments

First of all, I want to thank my committee members, especially co-chairs Dr. Thomas Hester and Dr. Samuel Wilson, who interceded on my behalf many times with the Department of Anthropology and the Graduate School, as well as the other members, Drs. Michael Bever, Michael Collins, Darrell Creel, and Ernest Lundelius, Jr. Unfortunately, they had to read all the text that follows. In particular, I couldn't have gotten through this without Sam, who bent all the rules way beyond the elastic modulus.

I must also thank the field crew, both paid and volunteer, who endured the freezing cold, when it got so bad that just holding a pencil to write was nearly impossible, ignoring the chilling drizzle settling out of the raw December sky, and straining against the cold gray winter light to see their field notes with a bitter wind whipping their backs. And that was merely what it was like in the crew house! Will Goetzmann, Dan Potter, Lang Scruggs, and Don White comprised the UTSA-CAR crew. Victoria archeological stalwarts Bill Birmingham, the late Smitty Schmiedlin, Mark Terry, Sonny Timme, and Ed Vogt rendered inestimable help; Bill not only helped on the site, but also loaned his own personal equipment many times. Special thanks also go to Sonny, who first found the hearth and recognized it for what it was. Let us also not forget that these Victorians were the first archeologists to locate the Berger Bluff site and bring it to the attention of the CAR survey team. Other volunteer workers were

Grant Hall and Erwin Roemer, Jr. of the CAR, both of whom took a day from busy schedules to come down and help when I needed it most; Cindy White, who helped with mapping; and Joan DeCosta, who helped set duplicate primary datum points and collect soil samples from the upper deposits. Crew members Ralph Snavely and Chuck Suhler and backhoe operator Lloyd Barefield helped in 1983 with testing in advance of Flume #3 construction; that project is reported elsewhere, and provided geological information on area B of the Berger Bluff site, information which helps us understand the origin of some of the upper deposits.

I also want to thank the original owners of the land on which the site is located. Leslie Berger and Noel Dietzel allowed us to cross their land to get to the site. Mr. Berger and Nelson Pantel, who owns the land across the creek, also helped answer some of my questions about the history of the site environs. Stan Pantel (Nelson's nephew) and Earlene Madden visited us out of curiosity, then became friends as we spent a few pleasant evenings on the Pantel place, fortified with Lone Stars around a mesquite-stoked campfire. Stan, this one is for you. I understood your strong sense of belonging for the Coleto, and I expect others before us have felt it too.

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Special thanks, too, go to Glen Evans, who briefly examined the stratigraphic section during David Brown's excavations and who provided the beginning stratigraphic framework necessary to interpret the depositional history of the site. Charles Winker, whose excellent master's thesis (Geological Sciences, UT Austin) provides another kind of framework, this one dealing with the Quaternary evolution of the Gulf coastal plain, visited the site and looked at the stratigraphy, and loaned me a copy of his thesis, which has proved very useful.

Several people helped with an attempt at thermoluminescent dating of the hearth, later abandoned. The late Dr. Don Lewis (UTSA) supervised this aspect and taught me something about the mechanics of the technique. Dr. Clara Ho (Director, Mineral Studies Lab, Bureau of Economic Geology, UT Austin) provided the potassium analysis of the hearth sediment. David Cadena (Southwest Research Institute) provided irradiation of hearth sediment samples. Steve Black and Paul Lukowski (formerly UTSA-CAR) assisted with alpha-counting. Although this effort was not successful, all this help is no less appreciated.

Pat Wallace and Maggie Gage recovered the microscopic snails from the sediment samples, and I especially want to thank Maggie for her meticulous efforts in this work. Thanks to her we acquired some excellent data which proved to be critical in

understanding the site. Dr. Raymond Neck (former biologist, Texas Parks and Wildlife Department), a contributor to this report, analyzed the microsnail fauna and confirmed my identifications of the freshwater mussels from both the upper and lower deposits.

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about a cubic meter of fill from one of the excavation units. He also re-examined some of the animal bone, including the microtine specimens. And I swear that Ernie carried more of that stuff up the bluff than anyone else. I'll never forget him with a bag of wet sand over each shoulder and another under each arm, waiting patiently on a six-inch ledge as I struggled to drag one bag up the footpath to the top of the bluff. Boyce Cabaniss, who did the vertebrate paleontological analysis and who is also a contributor to this report, and Ann Warren (both graduate students in geology at UT Austin at the time) visited the site at the same time and also helped carry matrix up the bluff. Boyce also washed and sorted the matrix, a thankless job if there ever was one. Dr. Michael A. Schmerling assisted with SEM studies of fish vertebrae.

The first numerical studies that I did of some of the Berger Bluff data were done so long ago that they were done with mainframe computers, and several people helped with computer work. Liz Frkuska (CAR), Dr. Solveig Turpin, and Sue Boinski (Zoology, UT Austin) managed to beat assorted computers into submission for me, both in Austin and in San Antonio. Ultimately, the work was redone with modern desktop computer and software.

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data, repeatedly checked my drafts of the diatom chapter, and identified diatoms that I had photographed for illustrations. She provided advice, consultation, and taxonomic expertise on many occasions. Robert G. Howells (Texas Parks and Wildlife Department, Inland Fisheries Division) identified freshwater mussels from the Coleto Creek catchment and provided unpublished freshwater mussel data.

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The Bench Deposits at Berger Bluff: Early Holocene-Late Pleistocene Depositional and Climatic History

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Kenneth Martin Brown, Ph.D.

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Supervisors: Thomas R. Hester and Samuel M. Wilson

This study reports original field and laboratory studies on paleoenvironmental aspects of the Berger Bluff archeological site (Goliad County, Texas). It uses data from geoarcheology (stratigraphy, grain-size analysis, magnetic susceptibility and sediment thin sections) and several different biotic indicators (chiefly diatoms, snails, freshwater mussels, and vertebrates) of environmental change to reconstruct past environments of the site and upstream drainage, and relate these events to regional and global paleoenvironment.

Berger Bluff is a sandy bluff about 9 m high on the west, or Goliad County side of Coleto Creek, west of Victoria. The bluff (41 GD 30A) records continuous deposition of sediments by Coleto Creek from the Late Pleistocene until the Late Holocene. The lowest 2.45 m of deposits form a prominent erosional bench from floodplain sediments cemented by phreatic carbonate, probably representing the fossilized damp margin of a

spring or seep area, although no actual spring conduit was visible. Based on a series of radiocarbon assays, they are estimated to date from about 8500-11,000 radiocarbon years before present (or 9500-13,000 calendar years), but there are no assays from the upper or lower part of the bench, and there are a number of inversions among the assays. This corresponds to the Younger Dryas, Preboreal, and part of the Boreal period in the climatic chronology, and the Folsom and Late Paleoindian periods in the cultural chronology, although none of the artifacts from the bench are time-diagnostic.

The bench consists of fine-grained overbank deposits (cyclically bedded sandy and muddy units) formed by vertical accretion near the south valley wall. Sedimentary evidence suggests the creek was probably narrower, deeper, more sinuous, and carried a much greater suspended load during the Younger Dryas/Early Holocene compared to today. Rainfall was probably less seasonally concentrated, discharge less flashy, and flood duration longer. The floodplain was probably wider, flatter, less drought-prone, and (based on evidence from snails and vertebrates) covered with a heavier, more continuous deciduous tree canopy than today. These conditions probably lasted some 1500 years into the Holocene, until regional drying and flash flooding stripped the wet riparian habitat out of Coleto Creek and other small tributaries on the Gulf Coastal Plain.

Keywords: Berger Bluff, Goliad County, Younger Dryas, paleoenvironment, geoarcheology

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Chapter 1: Introduction

THE SITE

Berger Bluff is an archeological site located near the city of Victoria, on the Gulf coastal plain of Texas. Cultural debris is scattered at various levels, possibly throughout this eight-meter high bluff fronting on Coleto Creek. This is a study of paleoenvironmental data from the earliest and most deeply buried part of the site — the "bench" deposits, thought to date from about 8500-11,000 radiocarbon years before present [a brief discussion of kinds of years (radiocarbon and calendar years) and dating problems will be found at the head of the next chapter]. From an archeological viewpoint, the most interesting and significant find in the bench deposits is a small concentration of animal bone believed to represent human dietary remains (Brown 1996), but the vertebrates will not be addressed in this study except as environmental indicators; other kinds of cultural debris will only see brief mention.

The environmental history of this part of Texas is not very well known, especially for this relatively early time. Most of the emphasis here is on climate as the paramount driving force behind environmental change. I will begin by briefly reviewing — from a global perspective — two key concepts of climate change (rapidity or *abruptness* and *cyclicity*) and our prospects for recognizing them in the archeological record. Because there is clear evidence for cyclic sedimentation in the bench deposits, the key problem here is to determine whether changes in the sediments are driven by repetitive changes in regional climate, looking for patterned changes in biota (mollusks, diatoms, and vertebrates) at stratigraphic boundaries to answer this question.

I will also argue that new data and research methods should spur Texas archeologists to rethink conventional notions of how environments changed at the end of the last ice age. The main purpose of this first chapter is to give the reader an overview of environmental changes at the Pleistocene-Holocene transition from a global viewpoint, and in the second part of this chapter I will review the history of site excavation and the contemporary climate, vegetation, and hydrology of the study area. In Chapter 2, I will narrow the focus both chronologically (looking at the 8500-11,000 BP period) and geographically (looking at environments in the Guadalupe and San Antonio River drainage basins and at changes in the adjacent Gulf of Mexico). Matters such as radiocarbon calibration, changing sea level, and comparable paleoenvironmental sites will be discussed there.

Paleoclimates and paleoenvironments

The term "paleoenvironment" refers to past environmental conditions: plants, animals, climate, soils, and depositional processes. The term "paleoclimates" refers to past atmospheric conditions, and although climate is only one part of the environment, it is generally thought to be a prime mover affecting not only depositional processes, but the distributions of plants and animals as well. Other kinds of paleoenvironmental forces have been identified (plant or animal pathogens, for example, or fires set by people), but none seem to be as important as climate for modifying the environment, which is why many of the following pages will be devoted to looking for a climatic signal in the environmental data from Berger Bluff.

THE PROBLEM: ABRUPT OR GRADUAL CLIMATE CHANGE AT THE DAWN OF THE HOLOCENE?

Human occupation of Texas spans the frontier between two geologic epochs: the Pleistocene (which begins at least 1.8 million years ago, before human entry of the New World, and lasts until about 10,000 radiocarbon years before the present) and the Holocene (from the end of the Pleistocene to the present). These two geologic epochs have climatic meaning as well, and the climatic transition between the two was perhaps the greatest environmental challenge ever faced by the native occupants of North America until the advent of European exploration.

This transition in Texas has been viewed (based chiefly on fossil pollen evidence acquired during the 1960s and 1970s) as one of gradual, non-episodic warming and drying (Bryant 1969:145; Bryant and Holloway 1985:56). Bryant and Shafer (1977: 19) go so far as to assert that "...the changes were demonstrably gradual, occurred over several thousand years and probably went completely unnoticed by successive generations of aborigines." This model of climatic transition has now probably taken on the status of received wisdom among most Texas archeologists, and is still accepted by other archeologists elsewhere, like Michael Jochim, who asserts "...that seemingly discrete environmental stages are a product of poor chronological resolution. In reality, environmental changes were generally slow relative to human lifetimes and would have been perceived as gradual changes in relative proportions of habitats and resources, not abrupt replacements" (Jochim 1996:358). Some Texas archeologists and paleontologists, however (cf. Bousman 1994; Collins 1995; Holliday 1995; Toomey, Blum, and Valastro 1993), have called attention to empirical evidence for alternating wetter and drier periods

in the late Pleistocene and Holocene, although none have explicitly addressed the question of abruptness. As Thompson (1981) has shown in an interesting review of American cultural attitudes toward climatic stability, the view of climate as immutable or imperceptibly changing actually originates in the late nineteenth century.

Holloway and Bryant (1985:xii) maintain that "in Texas there does not appear to be a sudden vegetational shift marking the traditional end of the late-glacial and the beginning of the Holocene. Instead, what seems to be evident is that by 10,000 yrs. B.P. the Holocene character of the vegetation in that region of North America is firmly established. In another region of North America, the Great Lakes...the close proximity of that geographical area to the retreating ice sheets created a much quicker climate shift which is expressed vegetationally as a rapid change over the relatively short period of...1,000 years."

Climatologists Reid Bryson and Wayne Wendland are two of the chief American critics of this model of gradual, monotonic change. Referring to Holocene climates, Bryson explains,

> Prior to the introduction and widespread use of dating methods such as radiocarbon, and the availability of detailed time-profiles of climatic proxies, the concept of Holocene climatic variation was one of slow "warming" to some optimum followed by a similarly slow monotonic "cooling". Warming and cooling were ill-defined and, by context, could be referred to as regional to global....As the volume of evidence grew, it became clear that the idea of a smooth simple variation was untenable. With detailed analyses, especially by European palynologists, distinct times of more rapid change were recognized, as well as details that suggested moisture variations that did not parallel the temperature inferences. The concept arose of distinct episodes, internally fairly homogeneous but with rather rapid transitions at their termini. This concept is now associated with the work of Blytt and Sernander, two palynologists. On the

> basis of qualitative evaluation of the European pollen record, they divided the Holocene into a series of episodes identified as being warm and wet, cold and wet, warm and dry, and cold and dry (Bryson 1987:1).

Wendland and Bryson have likewise adapted the Blytt-Sernander scheme for North America (Wendland 1978). Notwithstanding their periodization, we now know that, contrasted with the rest of the Quaternary, the Holocene has been a period of comparative stability (Ditlevsen, Svensmark, and Johnsen 1996) although climatic changes, including some abrupt ones, have occurred. Our own Holocene climatic experience has probably influenced our perception of how much abruptness is plausible. But as paleoclimatologists know, the Holocene is not representative of the Quaternary as a whole.

Paleontologists and archeozoologists have been far more willing than palynologists to interpret their data in terms of episodic climatic change, at least for the Holocene. An early example is Dillehay's (1974) postulated bison presence-absence periods, which he suggested were climatically driven. Paleontologists and archeozoologists working with Holocene data in the northern Midwest and adjacent Plains (cf. Semken and Falk 1987) frequently use Wendland and Bryson's framework of climatic episodes (Wendland 1978:Table 3), which is an expansion (with age modifications) of the European Blytt-Sernander scheme.

Another problem arises from periodic disruptions of thermohaline circulation in the world's oceans. Global circulation of seawater (varying in density according to salinity) not only redistributes heat from equatorial to polar regions, it also redistributes ^{14}C between the ocean deep, the surface, and the atmosphere (Broecker 1995). When

circulation is interrupted, or replaced by intermediate water formation (a shallower circulation mode that can drop sea surface temperatures by 5° in less than 10 years; Rahmstorf 1994), both climate and oceanic-atmospheric radiocarbon equilibrium are changed (Stocker and Wright 1996). The result is what is known as a "radiocarbon plateau," an extended period of ambiguity in radiocarbon dating, signaled in calibration programs like CALIB or OXCAL by multiple crossing points. The calibration programs can only quantify the ambiguity, not remove it; instead, we must turn to other methods like varve counts for precise dating. Ironically, then, it is at these very critical periods of climatic reorganization, the transitional periods of great interest to archeologists and paleoclimatologists alike, that the radiocarbon dating method breaks down and yields less precise age estimates (plateau effects can also be produced by variations in the rate of ^{14}C production in the atmosphere; Taylor 1987:24-33). Since cosmic ray flux is also positively correlated with cloud cover, at least on a short-term basis (Svensmark and Friis-Christensen 1997), there may be other linkages between climate and radiocarbon production rates as well. I will identify and discuss the radiocarbon plateaux relevant to Berger Bluff in more detail in the next chapter. For the time being, I suggest that this is one of the factors that have impeded recognition of abrupt climatic changes in the past. Ironically, at some of the climatic thresholds of greatest interest, where we particularly need precision in order to identify abrupt climatic events, radiocarbon assays can only provide *reduced* precision instead. One of these thresholds, unfortunately, is the Pleistocene-Holocene boundary.

The bench deposits at Berger Bluff bridge this transition between the Pleistocene and Holocene. Somewhere, about midway through the section, is a buried surface representing this time boundary, yet it is not visible, nor does it appear to be marked by

any abrupt changes in biotic content. This might be taken as an argument in favor of the Bryant-Shafer model of gradual change, but as we will see, there is some evidence of abrupt change that lags at least 1500 years behind the onset of the Holocene elsewhere. When discussing the Pleistocene-Holocene transition, most archeologists have focused on 1) megafaunal extinctions, 2) the creation of new estuarine habitats, or 3) the evolution of conditions favorable for agriculture. I will instead examine the evidence for habitat deletion on the Texas Gulf coastal plain.

New data suggest abrupt climate change

Meanwhile, new data and methods have arrived to challenge the prevailing view of gradual climatic change. Much of the new research is motivated (and funded) by concern with global warming. The first generation of analytical results from deep cores drilled more than three kilometers through the ice pack at the summit of Greenland by the Greenland Ice Core Project (GRIP, a multinational European Science Foundation project, with drilling in 1990-1992) and the Greenland Ice Sheet Project Two (GISP2, a US project drilled in 1989-1993) are now available (Alley 2000a, b; Johnsen *et al*. 2001). Unlike the Antarctic ice cores obtained earlier (Vostok, Byrd, and others), the Greenland cores can be dated with almost annual precision down to about 50,000 calendar years BP, and the results suggest that at the end of the Pleistocene, the ice accumulation rate doubled in just three years, with most of the change occurring in a single year (Alley *et al*. 1993:529; Fig. 2). Likewise, the ^{18}O signal in the ice jumped by about 4 ‰ in 20 years (Stuiver, Grootes, and Braziunas 1995:350, Figs. 10, 11, 13). The $\delta\,^{18}O$ content is a proxy measure of temperature, with about 0.25 ‰ corresponding to a one-degree Celsius change in temperature (Stuiver and Grootes 2000:278). Insoluble dust concentrations decrease from Pleistocene to Holocene levels in about 10 years (Zielinski

and Mershon 1997:550); alkaline dust concentrations fluctuate abruptly over periods less than 10 years long (Taylor *et al*. 1993:435, Fig. 2). Stuiver and Grootes (2000) studied 13 of the cold-to-warm transitions in the late Pleistocene-early Holocene and found that the onset is typically very fast (the midpoint is reached in only two years), peaking in about 50 years. Figure 1.0 shows a couple of examples of abrupt climatic change at the onset of the Holocene. Fig. 1.0, panel "a" shows a very abrupt decrease in calcium content in the GISP2 ice core at the end of the Younger Dryas (11,640 calendar years BP).

A recent summary statement by Taylor *et al*. (1997) is based on several years of study of all the various climate proxies from the GISP2 core. They conclude that

> ...the transition between the Younger Dryas and Holocene climate periods occurred over a 40-year period.... most of the transition occurred in a series of steps with durations of about 5 years. Some climate proxies associated with mid-latitude sources appear to have changed about 15 years before climate proxies associated with more northern regions (Taylor *et al*. 1997:825).

Ice accumulation rates increase as the temperature rises, and this was initially interpreted as a 7° C (12.6° F) warming (Dansgaard, White, and Johnsen 1989), later revised with isotope and borehole temperature data to a 15° (27° F) warming from "average glacial conditions" to the Holocene and a 20° (36° F) warming from the Late Glacial to the Holocene (Cuffey *et al*. 1995; Cuffey and Clow 1997). Johnsen *et al*. (1995) have derived an even more extreme estimate of 22° C (about 40° F), but note that these last estimates of 15° to 22° C pertain to much longer (unspecified) timespans than three years. A similar event appears in Scandinavian marine cores as a rapid (about 80 years) warming of surface water (about 9° C) at about 10,200 radiocarbon years BP (Jiang and Klingberg 1996; Karpuz and Jansen 1992: Fig. 9, 510, reproduced here as Fig. 1.0, panel "b").

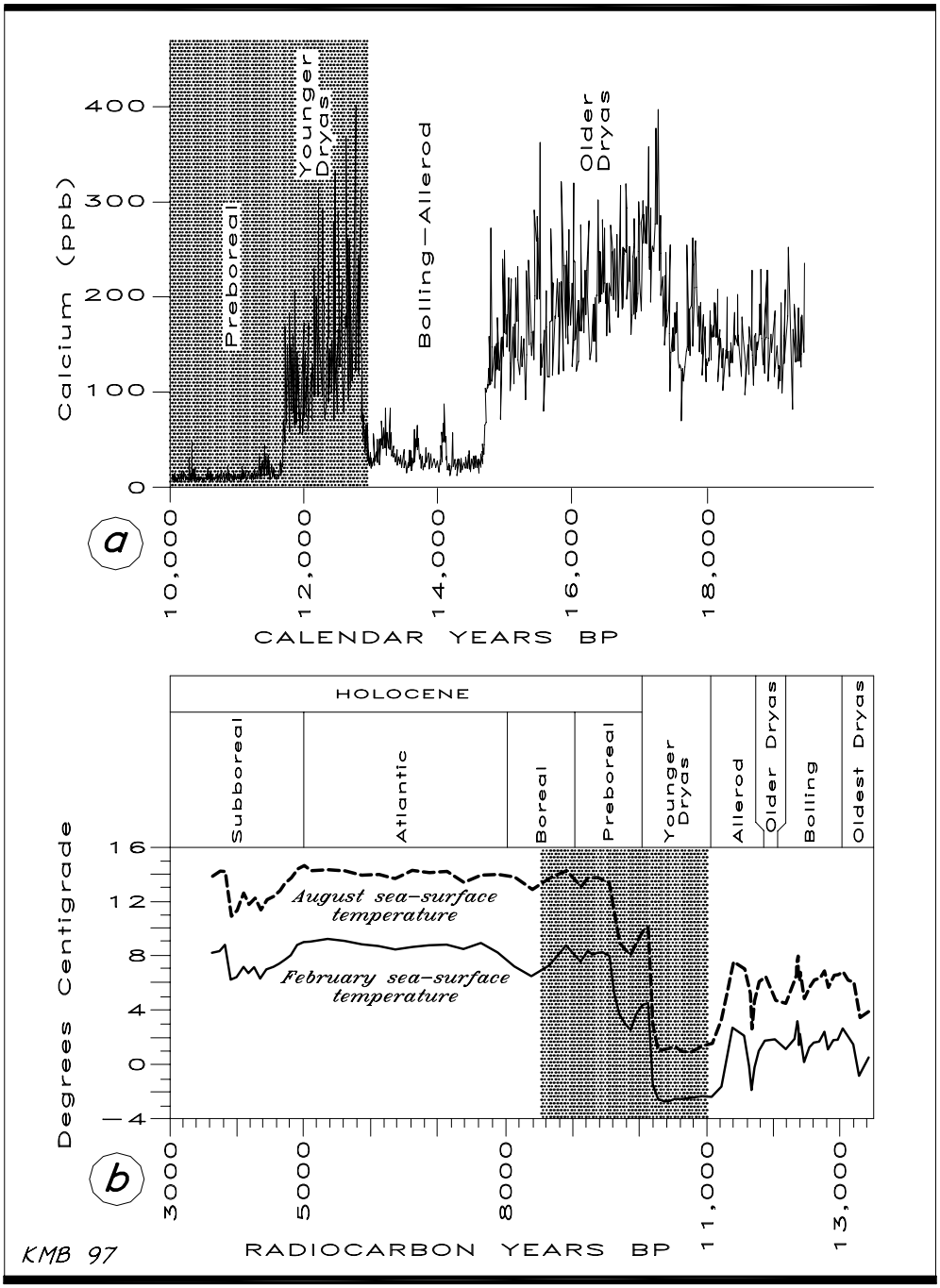


Figure 1.0. Abrupt Climatic Change at Onset of the Holocene. *A*, abrupt Preboreal calcium decrease, GISP2 ice core (Mayewski *et a*l. 1993:Fig. 1). *B*, sea-surface temperature rise (7-9° C), 10,200 radiocarbon years BP, North Atlantic core HM79-6/4 (Karpuz and Jansen 1992:Fig. 9). Time span of Berger Bluff bench sediments is shaded.

Modeling of nitrogen and argon fractionation in the GISP2 core suggests a 5-10° C step increase over a matter of decades, with a 15° increase after about 1500 years (Severinghaus *et al*. 1998:145). In boreal or littoral areas, at least, abrupt changes of climate like these would presumably have posed a severe environmental challenge for human populations — a survival problem perhaps not covered by the existing cultural repertoire. If the most rapid flux occurred in less than a single human generation, could the direct impact of such an event be recognized somewhere in the archeological record? The abrupt warming event seen in the GISP2 core occurs about 160 years after the most recent securely dated Folsom component (Taylor, Stuiver, and Reimer 1996:665) and perhaps midway during the accumulation of the bench sediments at Berger Bluff.

Cuffey *et al*. (1995) point out that estimates of the same transition in low mid-latitude areas are about 4° to 6° C, but global temperature changes are magnified in the Arctic. This evidence of dramatically abrupt change has led to a new model of climatic "mode-switching" involving changes in atmospheric and North Atlantic Deep Water circulation (Fairbanks 1993) and episodic dust loading (Overpeck *et al*. 1996). A new Antarctic ice core to be drilled by the European Project for Ice Coring in Antarctica (EPICA) is planned for the years 1996-2000 and may eventually provide southern hemisphere data comparable in quality and extent to that of the Greenland cores.

What happened in continental interiors?

If Arctic temperatures jumped dramatically by 22° C, or even a more conservative 7° in just a few years at the threshold of the Holocene, what happened in the continental interior of North America, particularly in lower latitudes? Temperature departure or "anomaly" maps (maps of the calculated difference between modern and glacial

conditions) produced by climatic modeling suggest that the most extreme temperature differences between present and full-glacial or late glacial climates were markedly concentrated in the polar regions, especially in the northern hemisphere (Peteet 1987:Fig. 2, 11,000 BP; Kutzbach 1987:Figs. 3, 7; CLIMAP Project Members 1981:Maps 5A and 5B, 18,000 BP). If, as it now appears, changes in ocean circulation were a major cause of abrupt climate changes (see Bond 1995), the process would have been global, but the most dramatic effect would have been in the north Atlantic region (northeastern North America, Greenland, and Europe). Analyzed at 200-year intervals, pollen records from the eastern US show "rapid" rates of change at the onset of the Holocene, but chiefly between about 40° and 50° latitude (Grimm and Jacobson 1992:181). Studies of fossil chironomids from lakes at about 49° N in British Columbia show a dramatic rise in July air temperature from the Younger Dryas into the early Holocene, perhaps as much as 7-9° C (although the radiocarbon dating is not well resolved; Palmer *et al*. 2002:Fig. 8). Temperature departures in more southerly latitudes, especially near the Gulf of Mexico, must have been less extreme. Indeed, simulations of other variables such as surface winds, precipitation departures, and atmospheric pressure suggest departures were much less pronounced over Texas than in boreal regions (Kutzbach 1987:Figs. 4-6, 8-10). Empirical studies of glacial-aged proxy data also suggest that temperatures rose steeply away from the southern border of the Laurentide ice sheet (about 1.3 to 3.0° C of temperature per degree of latitude, compared to 0.3 to 1.0° C for the same region today; Curry and Delorme 2002:199). At Bellefontaine Quarry near St. Louis, ostracod data indicate mean annual temperature was about 10° C below today (Curry and Delorme 2003). In Texas, studies of chlorine isotopes and noble gas content in groundwater from Atascosa and McMullen County suggest the mean annual temperature was about 5° C lower at 12,000-17,000 RCYBP than at present (Stute *et al.* 1993). Packrat midden data

from the same timespan in south-central New Mexico suggest a July maximum temperature depression of 3.5° to 5° C (and a climate about 20% wetter than present; Betancourt *et al*. 2001). A similar difference of 5.4±0.7° C for the San Juan basin was obtained by Stute and Bonani (1995). Packrat midden data from southern Nevada suggest mean annual temperature was about 8° C colder than today at 20,500-18,000 RCYBP, and about 5.5° C colder at 14,000-11,500 RCYBP (Thompson, Anderson, and Bartlein 1999a:34). Dutton (1995) suggests that middle to late Wisconsinan recharge temperatures of groundwater on the Llano Estacado were about 5-8° C cooler than average Holocene temperatures. However, note that Johnson (1987:98) estimates that Clovis period winter *minimum* temperatures at Lubbock Lake were about 0° C, compared to -18° C today, with the summer *maximum* about 28° to 32° C, compared to 38° C today. Terrestrial records from tropical and subtropical areas suggest late glacial sea surface temperatures were 4.2 to 8° C cooler than at present; strontium/calcium temperature estimates from coral reefs in the southwest Pacific show sea surface temperatures about 4-6° C colder than today at about 9350 radiocarbon years BP (Beck *et al*. 1997; Gagan *et al*. 2000). A more recent review puts tropical sea surface temperatures at about 2.5° C cooler than present at the last glacial maximum (Crowley 2000; see also Lea, Pak, and Spero 2000).

Unfortunately, most of the general circulation models that have been done so far have been run at 3000-year intervals on grids that are about 250-800 km in size, and these are far too coarse-grained to address the problems of abruptness or spatial variation on a scale that is of interest to archeologists. According to Kutzbach and Ruddiman (1993:12), 3000-year intervals were chosen because bioturbation in ocean cores was thought to prohibit finer resolution, and models were run at 12,000 BP and 9000 BP specifically to avoid periods of rapid transition such as that at 10,000 BP. Studies of general circulation

models at different resolutions have shown that resolution affects the spatial accuracy of the models (Dong and Valdes 2000). More recent research has shown that sampling of marine cores at 1 cm intervals can provide century scale resolution, despite the effects of bioturbation (Chapman and Shackleton 1998; but see also D. Anderson 2001). A more recent modeling study by Bartlein and others (1998:Fig. 5, 6) suggests that in the early Holocene (about 9900 RCYBP), winter temperatures did not greatly differ from the present, the greatest summer temperature departures from the present are in the midwest and northern Plains, the greatest winter precipitation departures from the present were located in the Rocky Mountain area, and the greatest summer departures were in Florida and the midwest.

Long, but very fine-grained terrestrial records are needed for comparison with the ice core record, and varved lake sediments are probably the only kind of record that can approach the continuous detail seen in the ice cores (Colman 1996). In the last couple of decades, some palynologists have begun to extract samples as thin as 2 mm, with each sample in some cases representing as little as a couple of years of accumulation (Turner and Peglar 1988:754). Unfortunately, while many of the existing deep lake cores show clear evidence of major excursions by various proxy measures near the Pleistocene-Holocene boundary, the sediment cores are often dated not by varve counts, but by radiocarbon assays that are too few and too widely spaced (intervening segments are "dated" by interpolating sedimentation rates). As a result, there is often evidence of environmental change, but it is impossible to tell how rapid it was, or exactly when it occurred. The ice core data have posed an entirely new research question that paleolimnologists need to address by targeting the parts of their cores that span the Younger Dryas-Preboreal transition for very close-interval studies, with multiple AMS

assays, if necessary. The discovery of rapid change in the Greenland record has stimulated the search for comparably resolved paleolimnological records from continental interiors, but because these findings are so recent, it will be a few years before these studies are completed. A number of high-resolution records from freshwater lakes have recently become available, but many (Butler 1985; Bradbury and Dean 1993) are from sediment cores extracted before the Greenland research. Previous records like the Oxford Lake-Levels Data Bank (tabulated in thousand-year units) are too coarse-grained to address the question of rapid change. New programs are getting underway, like the European Lake Drilling Programme (ELDP), another European Science Foundation project to run from 1996 to the year 2000, and here in the US, the National Oceanic and Atmospheric Administration (NOAA) has likewise funded some paleolimnological studies in the northern Plains, although there are not many sites in that area with records that reach into the Pleistocene. Recent research at Kråkenes Lake on the western coast of Norway ought to serve as a model for research on the Pleistocene-Holocene boundary in lake cores. At Kråkenes, Holocene samples analyzed were 1 cm thick and Younger Dryas samples were 2 cm thick or less, depending on the thickness of laminations, and dating is fixed by over 70 AMS assays and some known ashfalls (Gulliksen *et al*. 1998).

Continental climates show marked seasonal extremes and are not buffered by adjacent water bodies. Figure 1.1 shows an isopleth map of Conrad's continentality index for North America, along with the location of Berger Bluff (site 1) and some key lacustrine records that extend near or beyond the Pleistocene-Holocene boundary. Areas with high values are climatically sensitive. As the map shows, some of the key records are not located in climatically sensitive areas, and the central and southern Plains regions are poorly represented.

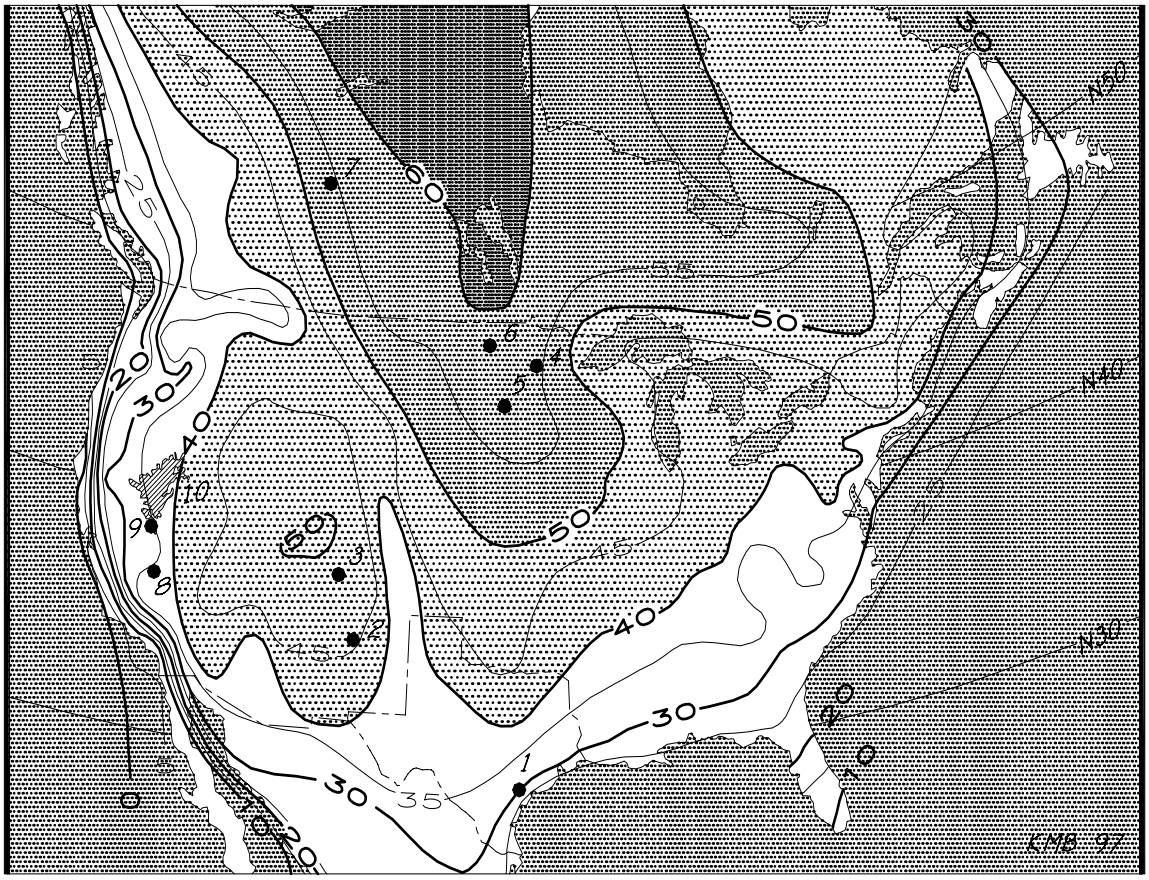


Figure 1.1. Isopleth Map of Continentality for North America. Contemporary distribution of continentality (seasonal severity of climate), based on Conrad's (1946) continentality formula (after Trewartha 1961:Fig. 6.1). Some important paleoenvironmental sites are also shown, as follows: 1, Berger Bluff; 2, Lake Estancia; 3, Black Mountain Lake; 4, Elk Lake; 5, Medicine Lake; 6, Devil's Lake; 7, Moore Lake; 8, Owens Lake; 9, Walker Lake; 10, Lake Lahontan. Sites 2-7 are in climatically sensitive areas with very continental climates, but the Gulf of Mexico moderates climate at Berger Bluff.

Some new records are emerging from Devils Lake and Rice Lake (North Dakota), Owens Lake (California), and other sites. Projects such as PALE (Paleoclimates from Arctic Lakes and Estuaries) and the Taconite Inlet Project (Canada) have begun to look for well-preserved annually laminated lake sediments in boreal environments. Since most

of this new funding will inevitably be directed toward climatically or agriculturally sensitive areas such as the northern Plains and Midwest, the issue of how rapidly climate changed in areas such as Texas may not be resolved for some time. The answers must come from climatically sensitive lakes, that is closed basins with no input from tributary streams, with deep bottoms and rapid sedimentation rates. To approach the kind of resolution found in the Greenland summit ice cores, parts of the sediment cores from these lakes will have to be sampled at much finer intervals than the 5 cm or 10 cm intervals generally used in earlier work. Because Texas has few natural lakes except for the abundant playas of the Llano Estacado, there are few prospects for research of this kind in the state. Hovorka (1997) and others have found that some of these playas contain more than 10 m of sediments, and radiocarbon assays as old as 12,530 radiocarbon years BP have been obtained, but because these are seasonally dry lakes, the continuous varve sequences needed to detect abrupt climate change are probably not preserved.

Elsewhere in the world, a few records from continental interiors are beginning to emerge that suggest abrupt climatic change is not limited to boreal regions. Some of the best records are from Swiss lakes where sediment cores document a rapid shift toward more positive oxygen isotope values at the onset of the Holocene (Dansgaard, White, and Johnsen 1989); at Soppensee, for example, this shift is estimated to have taken about 50 years (Lotter *et al*. 1992At Gerzensee and Leysin, summer temperatures rose at a rate of about 0.3° C per 25 years at the start of the Holocene (Birks and Ammann 2000:1393). One of the best records is from Lake Gosciaz, in Poland, with a sample resolution of 1-4 years. Here, the Pleistocene-Holocene climatic transition spanned about 160 years, but in a series of stepwise phases, and the transitions between phases lasted 10 years or less. Major postglacial warming comprised an initial 20-year phase (11,520-11,500 cal BP) of

winter warming, followed by a second phase 40-year of warming at 11,500-11,460 cal BP (Ralska-Jasiewiczowa *et al*. 2003; see also Ralska-Jasiewiczowa *et al*. 1995:185). Other relatively fine-grained European records come from Ammersee in southern Germany (sample resolution = about 11 years; von Grafenstein *et al.* 1999), Lake Holzmaar, also in Germany (Zolitschka *et al*. 2000), and Lago Grande di Monticchio in Italy (Allen *et al.* 1999). Asian records include lake Qinghai in China (Yu and Kelts 2002), where the onset of the Holocene is marked by an abrupt increase in precipitation at 10,000 RCYBP. One of the best records anywhere is the 14,570-year long varve record from Lake Van in eastern Turkey, at about N 38° latitude (equivalent to Wichita, Kansas). Here sediment deposition rates increase abruptly by about 40% in just five years at the beginning of the Holocene (10,920 varve years BP, or about 9668 radiocarbon years BP; Landmann *et al*. 1996:113; Fig. 4A; Landmann and Reimer 1996). The best continental climate records come from these European lakes – many of them are varved, at least in part, have finer resolution, and have been more extensively studied. From these, it is clear that the onset of the Holocene was fairly abrupt, though not quite so rapid as portrayed in the Greenland ice cores. However, European climate is heavily influenced by the Gulf Stream and by North Atlantic climate processes.

By contrast, the North American lake record is much more sketchy, coarse-grained, and less well studied, in large part because the geological conditions are not as favorable as in Europe; and climate in North America is conditioned by the jetstream and by relative dominance of the Pacific, Gulf, and boreal airmasses. There are a few North American lakes that hint at how rapid the onset of the Holocene was. At Moore Lake in Alberta, cores were sampled at 5 to 10 cm intervals, and evidence was found for rapid replacement of the initial sagebrush-grassland association by spruce-birch forest between

about 11,600 and 11,400 BP (Hickman *et al*. 1996:166). At Devils Lake, North Dakota, freshwater diatom taxa were abruptly replaced at 8000 BP by salt-tolerant taxa indicating low water levels (Fritz *et al*. 1991). At Lake Estancia, New Mexico, the sedimentary sequence was sampled at 2.5 cm intervals (representing about 60 years) for detrital quartz and ostracods, documenting freshwater pulses that "lasted only a few decades and were separated by a few hundred years" (Allen and Anderson 1993:1922, 2000:Fig. 12; R. Anderson 2001). The freshwater pulses are attributed to increases in precipitation. These records suggest that abrupt climatic change at the dawn of the Holocene was not limited to the North Atlantic region.

Contributions from new technology

Two new developments since the original fossil pollen studies were done in Texas may help to revise earlier ideas about climate change. Commercial availability since about 1980 of accelerator or atomic mass spectroscopy (AMS) radiocarbon dating of small plant macrofossils now permits dating of lake sediments where varves are either lacking or obscured. The continued improvement in computers and decline in memory chip price may enable climatic modeling at a much finer temporal and spatial scale. Because general circulation models are three-dimensional (often with 9-12 vertical layers), they are computation-intensive. The application of networked computers may enable a new generation of finer-grained models.

Insects record rapid temperature change

Some of the best evidence for rapid temperature change at the onset of the Holocene comes from fossil beetles recovered from sediments, most often in lakes or bogs, but sometimes in drier settings. The pioneering work was done by G. Russell Coope in Britain. Because climatic tolerances of insects have not evolved significantly

during the Quaternary, maps of modern species distributions can be used to define the upper and lower thermal limits of each species in the assemblage (see Elias 1994:74-79). Elias remarks that

> Most changes registered in pollen spectra through the Quaternary have been gradual, with transitions between glacial and interglacial episodes lasting hundreds if not thousands of years. However, Coope's work began to cast doubt on paleobotanical reconstructions of climate during intervals of rapid change, especially during the late glacial interval. In fossil insect records, changes between faunas suggestive of major climatic episodes may occur in as little as a few decades, and are often so rapid as to appear instantaneous in the fossil record (Elias 1994:79).

In Britain, the insect data record abrupt warming just before 10,000 radiocarbon years BP. Maximum temperature shows an increase of about 7° C, but minimum (winter) temperatures show an even more drastic increase of about 26° C (Elias 1994:Fig. 5.3). Similar abrupt warming episodes are recorded in Sweden at about 10,200 BP and in southern France at about 10,000 BP (Elias 1994:Figs. 5.4, 5.5). In North America, insect data from the northeast suggest episodic or oscillatory warming beginning very early (before 16,000 BP), with modern July temperatures reached in Ontario by 10,000 radiocarbon years BP (Morgan 1987:Fig. 8; see also Elias 1994:Fig. 5.6). At Splan Pond in New Brunswick, summer surface water temperatures abruptly increase by about 3° C beginning somewhat before 10,100 BP (Walker, Mott, and Smol 1991:Fig. 2). Insect assemblages from the Rocky Mountains show the same trend (Elias 1996:Fig. 2), but unfortunately the samples are too widely spaced in time to address the question of abruptness. A sample at 12,000 radiocarbon years BP has January temperatures about 14° C below modern, while the next sample at 10,000 BP is about 7° C above modern (the mean July values are roughly 2° below and 3° above, respectively). It is interesting to note that here as in Britain, it is the winter temperatures that show the greatest flux (this

despite the fact that the insects are poikilotherms and are inactive in winter; Elias 1994:89). Chironomid assemblages from Greenstone Lake in California suggest July surface water temperatures increased steadily (with some oscillations) from the Younger Dryas into the early Holocene, increasing no more than 2° C in the millennium after 10,000 RCYBP (Porinchu *et al*. 2003:Fig. 6).

Fight or flight?

The history of Quaternary insect assemblages is one of relocation rather than extinction or evolutionary adaptation (Elias 1994:59-72). Insects are highly mobile, and Coope (foreword in Elias 1994:x) remarks that insect species responded to rapid climate shifts "by *moving* out of trouble rather than by *evolving* out of trouble." Since Paleoindian foragers have been characterized as equally mobile, we might ask whether Quaternary insects should serve as a useful model for human responses to rapid climate change. In cases of very rapid (one human generation or less) climate change, did Paleoindians simply relocate rather than seek new cultural adaptations? Persistent occupation of New England and eastern Canada through the vicissitudes of the Younger Dryas (see the next chapter) suggests that in some cases, the answer is no. If Paleoindian populations did relocate, would they seek out maritime areas where climatic extremes were buffered?

CYCLICAL CHANGES IN CLIMATE: SCALE AND RECOGNITION

Climatic changes are often thought to be cyclical (but see Burroughs 1992), meaning not only that some variable (such as temperature or precipitation) oscillates in opposing directions, but that the amplitude and frequency of the peaks occur with some consistency. Changes of climate also occur on many different time scales. Many of these occur on a wavelength that is much too long to find expression in the typical New World

archeological record. Paleoclimatologists know that glacial-interglacial cycles are caused by changes in the Earth's orbital eccentricity (in a cycle of 100,000 years) or inclination (Muller and MacDonald 1997), obliquity (41,000-year cycle), and precession of the equinoxes (23,000 and 19,000-year cycles; Imbrie and Imbrie 1986; Kerr 1996), but cycles of this length are far too long to show up in the archeological record, though part of a climatic hemicycle may appear as a unidirectional, monotonic trend. The Holocene warming that we have already discussed is a part of one of these cycles of course, but we can see only part, and even then only when the record is pieced together from many archeological sites.

At the opposite end of the spectrum are very short climatic cycles lasting a few years or decades. These are usually investigated using historical records of temperature, precipitation, or barometric pressure. *El Niño-Southern Oscillation* (ENSO) events, on about a 6-year cycle, or the quasi-biennial oscillation (Burroughs 1992:49, 60) are so frequent that we read about them in the newspaper. Cycles on a decadal-to-century scale have been ascribed to feedback effects in the coupled ocean-atmosphere system, solar variability, volcanic events, or variations CO_2 or methane content of the atmosphere (Rind and Overpeck 1995). But events like these are too short to appear (individually, at least) in the archeological record, especially a poorly resolved and time-averaged one.

Of more interest are climatic cycles that lie between these two extremes. Cycles a few centuries in length ought to be of an appropriate scale to show up in the archeological record. Many of these have been identified in the worldwide proxy record (Mann, Park and Bradley 1995; Stocker and Mysak 1992), although it has yet to be determined how many are statistically significant (that is, distinguishable from random variation). Stocker

and Mysak (1992) have ascribed such cycles to natural oscillations in the ocean-atmosphere system.

Oxygen isotope analysis of the Camp Century ice core suggests cycles at frequencies of 78 and 181 years (Burroughs 1992:80-81). Isotope analysis of the GISP2 core has revealed about seven different possible cycles ranging from 2.7 years to 69 years in frequency in the single-year resolution ^{18}O data set, while the bidecadal ^{18}O data set shows 10 different possible cycle lengths ranging from 120 to 3300 years (Table 1.1, based on Stuiver, Grootes, and Braziunas 1995). Any of the cycles listed here in the range from 120-1050 years might conceivably be displayed in sedimentary archeological contexts. Other cycles have been identified in Holocene lake sediment varves (30-40 years, Renberg, Segerstrom, and Wallin 1984; 25, 31, 44, 78, 100, 165, 200, and 270 years, Halfman and Johnson 1988; 22, 40-50, and about 200 years, Anderson 1993), dust content (400 and 84 years, Dean 1997), pollen content (1100 years, Overpeck 1987), beach ridges (18.2-23.4 years, Philip 1984; 72 years, Delcourt, Petty, and Delcourt 1996), Nile floods, rainfall and temperature records (Burroughs 1992:Table 3.2), tree-rings from the US (30 years, Stahle, Cleaveland and Hehr 1988; 15-25 years, Blasing, Stahle, and Duvick 1988; 18.6 and 11-year cycles, Kokus 1988), hydrogen and oxygen isotopes in tree-rings (various lengths from 55-156 years, Libby 1983:Table 2-1).

Table 1.1. Climatic Cycles Recognized in the GISP2 Ice Core (after Stuiver, Grootes, and Braziunas 1995:346).

One-year resolution data set (818 AD to present), ^{18}O data

Cycle length	*Possible source*
69 years	North Atlantic climatic system
29 years	
21 years	solar influence
19 years	lunar influence
16 years	
11 years	solar influence
2.7 – 6.3 years	ENSO events

20-year resolution data set (16,500 BP to present), ^{18}O data

Cycle length
3300 years
1050 years
550 years
465 years
314 years
264 years
242 years
211 years
155 years
120 years

20-year resolution data set (16,500 BP to present), ^{18}O and ^{14}C data (matching peaks)

Cycle length
70 years
61 years
44 - 46 years

To summarize, there is a hierarchy of climatic cycles driven by different forcing mechanisms. The *very long cycles* (about 20,000 years and up) are typically explained by astronomical forcing. *Very short cycles* (years to decades) have been extensively studied through historical weather records or tree rings and are not well explained but have been linked to lunar or solar cycles. In contrast, it is the *intermediate length* (century-length) cycles that are of most interest to archeologists, but these are understudied by comparison, and efforts at explanation have not gotten very far. Researchers seem to suspect some sort of variation in the coupled ocean-atmosphere system. Cycles in the millennial range are often explained by mode-switching in thermohaline circulation.

PRECIPITATION AND ATMOSPHERIC CIRCULATION

Up to this point, most of the discussion has dealt with changes in temperature. What about changes in rainfall and atmospheric circulation? Changes in temperature are important, since temperature controls evaporation rates, but changes in precipitation are even more critical since precipitation rates directly affect hydrology and moisture-sensitive biota (such as the snails and diatoms used as climate proxies in this study). Unfortunately, although the paleoenvironmental record can tell us something about *cyclicity* and *magnitude* of change in precipitation (as well as origin of airmasses), it is very difficult to address the question of *abruptness* except for the most recent part of the record, as documented by tree rings.

General Circulation Models: Ice Wasting Leads to Shifts in Storm Tracks

Climate modeling by the COHMAP team suggests that in late full glacial time (18,000 BP) the winter Polar Front Jetstream was split by the Laurentide ice sheet

(Thompson *et al*. 1993:500, Fig. 18.18) into northern and southern branches. Abrupt changes in the relative amounts of moisture transported by the northern and southern branches may have resulted in abrupt changes in Greenland ice $\delta\ ^{18}O$ (Stuiver, Grootes, and Braziunas 1995:351). In January, the southern branch, which now lies at about N 50°(about the latitude of Winnipeg), then lay at about N 30° (or about at the latitude of Smithville, Texas). Upper-level winds (and perhaps to some extent surface winds as well) were also stronger in some regions; for example, the maximum speed of the January north Atlantic jet was estimated at 40 meters/second, compared to 30 m/s now (Kutzbach and Guetter 1986:1742; 30 m/s is the arbitrary lower limit for wind speed of a jet stream by definition; Stringer 1972:227). The southward displacement was less prominent in July simulations (Kutzbach *et al*. 1993, compare Figs. 4.15 and 4.16). This southwardly displaced jetstream would have moved winter storm tracks along with it and would have brought greater winter precipitation (originating as Pacific moisture) to the Southwest (Kutzbach and Guetter 1986:1743; Dawson 1992:28, 138). For Texas east of W 101°, the COHMAP simulations suggest a January level of 0.16 mm/day of precipitation above the present (and 0.32 mm/day below present in July) at 18,000 BP (Thompson *et al*. 1993:500, Fig. 18.16). That works out to about 2.9 cm (roughly an inch) more of rainfall over a 90-day period, compared to the present. Under present climatic conditions, Pacific moisture is a significant source of rainfall on the Texas central Gulf coast only in winter and early spring, when large anticyclonic systems originating in the Gulf of California can track across northern Mexico, the Lower Pecos, and eastern Texas, moving from southwest to northeast. Most of our annual rainfall now, though, comes from moisture that originates in the Gulf of Mexico (this can be clearly seen on maps of Texas in which average annual rainfall steadily diminishes away from the Gulf).

Texas archeologists working with isotopic data should keep in mind that, if in fact full-glacial climates were characterized by much greater proportions of (winter) Pacific moisture than today, that moisture may have left a Pacific isotopic signature in Texas soil carbonates, organic carbon, and biota. Gulf of California sediments show evidence of low $\delta\ ^{18}O$ events at 8000-10,000, 12,0000, and 13,500-15,000 radiocarbon years BP, as well as a high $\delta\ ^{18}O$ event that may correspond to the Younger Dryas cold event (Keigwin and Jones 1990).

A computer simulation by Mock and Bartlein differs somewhat from the general circulation models described above and relies on finding present-day weather anomalies that are thought to be good analogs for paleoclimates at 18,000 and 9000 BP. Their analog for 18,000 BP shows most of Texas with precipitation levels similar to today, except for the lower Gulf coastal plain around Berger Bluff, which appears drier than today (Mock and Bartlein 1995:Fig. 3, B). This agrees fairly well with the simulation by Thompson and others, but does not discriminate between seasons.

As the ice sheet melted, the jetstream displacement effect diminished, and by 11,000 BP, when the period of concern for this study begins, the effect was considerably reduced, the winter jetstream perhaps lying at roughly N 40° (along the Kansas-Nebraska border; Thompson *et al.* 1993:500, Fig. 18.17). By 9000 BP, the COHMAP simulations suggest increased onshore flow of warm, moist air from Baja California in July (Kutzbach 1987:434). January precipitation over the eastern part of Texas is estimated at 0.27 mm/day below present, but July precipitation is estimated at 2.21 mm/day *above* present levels (Thompson *et al.* 1993:500, Fig. 18.16). That works out to 19.9 cm (about 7.5") of increased precipitation over the 90-day summer season, compared to the present.

When changing insolation values are used to estimate precipitation minus evaporation (P-E), the departures are less pronounced: 0.09 mm/day below present levels in January, 1.65 mm/day above present levels in July for 9000 BP.

This difference between winter and summer precipitation levels is worth noting. The present climatic regime for the eastern part of Texas is bimodal, with September and May the wettest months. According to the COHMAP simulations, late glacial precipitation would have been more plentiful in winter when annual ground cover is minimal, there is less interception of runoff, and loss to evaporation is minimal. This combination probably would have led to increased silt loads in streams and higher levels of winter groundwater recharge, indicated by steady spring discharge at Berger Bluff. According to the general circulation models, climate in the Southwest and eastern Texas was in transition from *winter-enhanced rainfall at 18,000 BP to summer-enhanced rainfall at 9000 BP*. By the time the bench sediments accumulated at Berger Bluff (8500-11,000 BP), the Gulf coastal plain climate was well advanced toward the summer-enhanced state, but the climate continued its transition toward the summer-enhanced regime. Whether the present bimodal September-May rainfall maximum was recognizable amid all these changes is still unclear. Reduction of winter rainfall probably resulted in greater loss of soil moisture to evaporation, reduced spring discharge, reduced silt loads in streams, and the disappearance of a significant Pacific isotopic signature. Under present conditions, heavy winter rainfall generally occurs only in years with *El Niño* events.

The simulation for 9000 BP by Mock and Bartlein (1995:Fig. 4, B) shows nearly all of Texas considerably drier than present, unlike the simulation by Thompson and others, which prescribes 0.95 mm/day of precipitation over present levels.

Much of our present springtime precipitation (and a good deal of the fall precipitation, as well) in Texas is generated when cold, fast-moving, Arctic airmasses penetrate the southern Plains and encounter Gulf moisture introduced by low pressure. The Laurentide ice sheet is thought to have blocked these meridional incursions of Arctic air during the full-glacial period, which is another reason why the present bimodal rainfall pattern would have been lacking in the Pleistocene, and why Pleistocene climates are thought to have been more equable (that is, lacking in seasonal extremes; Martin and Martin 1987; Auffenberg and Milstead 1965), allowing cold-intolerant taxa such as *Geochelone wilsoni* to survive at sites such as Domebo (Slaughter 1966:32), Lubbock Lake (Johnson 1987:65-66), Blackwater Draw, Friesenhahn Cave, and Buckner Ranch (Bee County; Moodie and Van Devender 1979) as components of disharmonious faunas (Lundelius 1989). Even as late as 10,000 radiocarbon years BP, the ice sheet still provided something of a barrier to airmass incursions, but by 8000 BP was diminished enough to open up the Plains to Arctic northers (Denton and Hughes 1981:Fig. 2-2; Andrews 1987:Fig. 7):

> The Boreal episode was initiated when ablation of glacial ice permitted arctic air to flow unimpeded onto the plains. Essentially modern biomes were organized by individualistic species response...as a result of colder winters along with warmer summers (Semken and Falk 1987:184).

The ice sheet also functioned as a reflective surface, amplifying polar cooling during glacial periods, and according to Webb (1986:86), "the climatic impact of its role

as an orographic barrier decreased faster than its role as a reflective surface." Meridional air flow may also have been enhanced in the early Holocene by another process, as well. The maximum seasonal contrast in insolation occurred about 10,000 BP. Since the strength of westerly flow (and hence strongly zonal circulation) depends on the temperature difference between equatorial and polar regions, increased summer insolation should lessen the latitudinal contrast, weakening westerly flow and encouraging a more meridional circulation pattern during the summer (with the opposite effect in the winter; Vance 1987:21, Spaulding and Graumlich 1986). The physical barrier presented by the waning ice sheet probably reinforced this effect (Vance 1987:Fig. 4). By 8000 BP, zonal circulation may have resumed (Vance 1987:27).

Empirical support

There is some empirical evidence that supports the modeled displacement of the jetstream. The latitudinal distribution of subfossil bison tracks its movement fairly well, especially in the late Holocene, at N 50° (McDonald 1981:Fig. 103). Packrat midden data from the Hueco Mountains and from the Sacramento Mountains in New Mexico indicate greater rainfall, mostly winter, in the late Wisconsinan (Van Devender 1990a:124-126; see also Allen and Anderson 1993 and Elias 1994:214), corresponding to a series of highstands in the nearby Salt Basin (Hudspeth County, Culberson County) from 15,940-22,570 radiocarbon years BP (Wilkins and Currey 1997). Spaulding and Graumlich (1986) cite packrat midden data from the Mohave Desert that suggests replacement of winter-dominant precipitation by summer monsoon rainfall at 8000-12,000 BP. This may also correspond to a period of low salinity and $\delta\ ^{18}O$ in the Gulf of California at 8000-10,000 BP (Keigwin and Jones 1990). Davis and Sellers (1987) have pointed out that for the period 11,500-7000 BP, lakes dried and xeric vegetation expanded north of latitude N

40°, while lake levels rose and mesic vegetation expanded to the south. In another paper, Davis (1989) disputes the shifting jetstream model and maintains that only its strength has varied in the late Quaternary, not its position. More comprehensive mapping by Thompson *et al*. (1993:Fig. 18.13) shows that the boundaries between wet and dry regions in the western US shifted over time, but the northern limit of maximum effective moisture at 9000 BP was positioned at about N 40° (Thompson *et al*. 1993:Fig. 18.14). They suggest increased monsoonal rainfall from southerly sources. There is widespread evidence from the southern Great Basin for wetter conditions in Late Glacial time. Packrat midden data from southern Nevada indicate mean annual precipitation 2.6 times modern levels at 14,000-11,500 RCYBP (Thompson, Anderson and Bartlein 1999a:34). The lake level history of Lake Lahontan in Nevada appears to have been heavily influenced by the position of the jetstream, showing a final rise in elevation by 10,500 RCYBP (Benson, Kashgarian, and Rubin 1995). Geologic and archeological evidence shows the floor of the Bonneville basin was wetter than at present from before 13,000 to 8800 RCYBP (Oviatt, Madsen and Schmitt 2003:208). The lake level history of Laguna Babicora in Chihuahua (Ortega-Ramirez *et al.* 1998; Metcalfe *et al.* 2002) also suggests wet conditions in the Late Pleistocene, particularly the Younger Dryas, due to winter rainfall and a southward displaced jetstream; Lake Chapala in Baja California likewise experienced higher levels before 9070±60 RCYBP (Davis 2003). Pollen and macrofossil data from Fracas Lakes and Bear Lake (northern Arizona; Weng and Jackson 1999), pollen from Lost Park (central Colorado, N 39°; Vierling 1998), and radiocarbon estimates of groundwater paleo-recharge rates from Black Mesa, Arizona (Zhu *et al*. 1998) suggest a similar pattern. The lake level history of Lake Estancia in New Mexico is rather poorly dated, but shows many fluctuations during the Late Pleistocene, with a final highstand bracketed between 11,500-9650 RCYBP (Allen and Anderson 2000;

Anderson, Allen, and Menking 2002: see Fig. 5) that is probably the result of jetstream displacement. Speleothems from caves in the Guadalupe Mountains, just north of the Texas-New Mexico border, have been dated by uranium-series dating, and show a period of growth from about 12,425±520 cal BP (roughly 10,505 RCYBP) to 10,613±498 cal BP (roughly 9475 RCYBP). This growth has been attributed to a wet period beginning in the second half of the Younger Dryas and lasting at least 500 radiocarbon years into the Holocene, as a result of jetstream displacement (Polyak, Rasmussen and Asmerom 2004:Fig. 2).

Site-specific climatic modeling by Bryson and Bryson (1996) suggests that the N 40° boundary extends eastward onto the Plains as well. Their modeling efforts suggest that sites in the northern Plains became progressively wetter from late glacial time through the Holocene to the present (Bryson and Bryson 1996:Figs. 6, 7, 11), while sites in the southern Plains became drier until about 10,000 radiocarbon years BP, then experienced a trend of slowly increasing precipitation (Bryson and Bryson 1996:Figs. 2, 5). Paleoclimatic modeling for Wyoming suggests the northern border of monsoonal precipitation and Gulf airmass incursions moved northward across the N 40° boundary at about 7000 RCYBP; this finds some limited support from estimates of C4 plant cover (Lovvorn, Frison, and Tieszen 2001:2488 and Fig. 3). However, the site-specific models for the northern Plains seem contradicted by other empirical evidence showing progressive aridification in the Holocene. Cores from a series of lakes in southern Alberta suggest severe drought from 10,000 to 6800 radiocarbon years before present (Beierle and Smith 1998).

Complications

Some of the empirical evidence from the Southwest challenges aspects of the above model. On the part of Fort Bliss extending into southern New Mexico (roughly latitude N 32º), pedogenic carbonates from buried soils in alluvial fans (Monger, Cole, and Giordano 1993) and basin floors (Monger 1993) furnished oxygen and carbon isotopes for study. The oxygen isotope values seem to show that late glacial or full glacial temperatures remained about the same as today (Monger, Cole, and Giordano 1993:Fig. VII-8) throughout the fan deposits, but shifted significantly toward warmer temperatures or summer precipitation after 16,000 BP in the basin-floor deposits (Monger 1993:91, Fig. VIII-1). In the fan deposits, $\delta\ ^{13}C$ values show major shifts toward more negative values after the full glacial, but these shifts ostensibly occur as late as 7000-8000 BP (Monger, Cole, and Giordano 1993:Fig. VII-7; Buck and Monger 1999). Except for a few charcoal deposits in the more recent sediments, these dates are based on radiocarbon assays of the carbonates themselves or on extrapolated dates for soils dated elsewhere from charcoal. The shift from more negative ^{13}C values seems consistent with a shift from winter rainfall-supported grassland to desert scrub, but the timing seems many thousands of years later than would be expected by the modeled migration of the jetstream. A similar shift occurs at Lubbock Lake (roughly N 33.5°) at 8200 BP and at Mustang Springs at about 7000 BP (Holliday 1995:55-56, Fig. 31), but here the shift is instead toward *less negative* ^{13}C values and from C3 grasses to C4 grasses, and the analysis is of organic carbon from sediments. Still farther north, in the central Plains loess deposits of Kansas and Nebraska, the record is longer. The same shift toward less negative values for organic carbon occurs, but in some places it occurs at about 10-11,000 BP (Johnson and Park 1996:Figs. 11, 15), at other places at about 8000 BP (Johnson and Park 1996:Figs. 12, 21), and the longer record provided by thick loess

deposits shows that the early Holocene shift is actually just one of several excursions in a long-term trend toward less negative values that begins *before* the full glacial at least as early as 23,000 BP. Connin, Betancourt and Quade (1998) studied carbon and oxygen isotopes in glacial-aged (mostly 10,000-55,000 RCYBP) herbivore teeth from the southwestern US and claim to have found significant evidence of C4 plants sustained by summer rainfall, in contrast to the winter-dominant model discussed above.

Haynes (1991) believes that a drought occurred over the Southwest and beyond at about 10,900 BP, followed by a return to mesic conditions. He is vague about the onset, magnitude, and duration of this supposed "Clovis drought," but if it was as brief and abrupt as he seems to imply, general circulation models cannot identify episodes at such short time scales. He himself notes that arroyos do not appear in the southwest until 8000 RCYBP (Waters and Haynes 2001). Site-specific modeling might reveal such an episode, but northward shifting of the jetstream suggests only continued drying of the Southwest at 10,900 BP, not the mesic reversal postulated by Haynes. Holliday (2000) argues for widespread drying and eolian deposition on the Southern High Plains at 10,200-10,900 RCYBP, a finding at odds with the evidence elsewhere in the Southwest.

This picture of northward-shifting storm tracks and seasonal shifting of rainfall regimes, as seen through the 3000-year thick time slices provided by general circulation modeling (and driven by ice sheet ablation and rising insolation rates) cannot account for short-term climatic events (such as Haynes's postulated "Clovis drought"), nor can it account for reversals in the climatic pattern (droughts followed by wet episodes). Thus, the features of *abruptness* and *cyclicity* identified in the paleotemperature record cannot easily be seen here, both because the precipitation model is too coarse-grained and

because the empirical record is less sensitive to precipitation changes than to temperature changes. Precipitation changes probably had more far-reaching effects on Paleoindians and the biota on which they depended, but we usually cannot detect these changes in the proxy record with the same fine-grained resolution and rapid response time with which Quaternary insects portray the temperature record. If there were dry or wet episodes, abrupt or cyclic in nature, during the Pleistocene-Holocene transition (such as the freshwater pulses at Lake Estancia), they must have been due to other causes, such as volcanic events that loaded the atmosphere with ash and sulphur compounds (the general circulation models used so far do not include aerosols), or atmospheric circulation changes that have nothing to do with gradual ice sheet wasting.

Volcanic aerosols

Volcanic eruptions, loading the atmosphere with fine-grained ash and sulphitic aerosol compounds, have been implicated in episodes of climatic cooling (Dawson 1992:180-198; Flohn 1979; however, see also Sadler and Grattan 1999). Mass and Portman (1989) examined historic weather records corresponding to known major eruptions since 1883 to determine whether volcanicity influences climate. They find that once the confounding effects of ENSO events are removed, only the largest eruptions cause cooling, that cooling only lasts for one to two years, and that temperature drops only about 0.1-0.2° C. They specifically address the possibility that volcanic aerosols might alter precipitation rates indirectly by shifting atmospheric circulation patterns (particularly toward more meridional flow), but find no relation between volcanicity and precipitation (Mass and Portman 1989:576, 589).

Mass and Portman's conclusions, however, are based only on a century-long sample of volcanic events; are they representative of the Quaternary? The ice core record shows that volcanic events may be clustered in time (presumably the result of episodes of crustal plate movement or isostatic adjustment to deglaciation). A major cluster of events between 16,000 and 20,000 BP corresponds to a 2-3° C cooling in the Byrd Station $\delta\ ^{18}O$ record (Dawson 1992:Fig. 10.4). Hammer, Clausen, and Langway (1997) further define this as a massive 170-year-long series of eruptions at about 17,500 calendar years BP (roughly 14,617 radiocarbon years ago) that produced an estimated 5-11 billion tons of atmospheric acids. A massive increase in sulfate flux between 13,713 and 13,531±520 BP (Bolling-Alleröd interval) in the GISP2 core could represent another period of volcanism (Mayewski *et al*. 1993:197). Mayewski has also identified a cluster of volcanic events at about 8000-12,000 BP that he attributes to stresses induced by isostatic rebound (lecture notes, October 9, 1997). Zielinski and others examined SO_4^{2-} concentrations in the GISP2 core for the last 9000 years and found that "there are three times as many events from 5000 to 7000 B.C. as over the last two millennia with sulfate deposition equal to or up to five times that of the largest known historical eruptions. This increased volcanism in the early Holocene may have contributed to climatic cooling" (Zielinski *et al*. 1994:948). See also Adams, Mann, and Ammann (2003).

Dust loading

Heavy levels of atmospheric dust have also been implicated as either a cause or a result of global cooling, and glacial periods are known to have been dusty (Overpeck *et al*. 1996; Taylor *et al*. 1993). On a long time scale (that is, tens of millennia), concentrations of dust in the polar ice cores are associated with cold periods. In the

Vostok (Antarctic) core, for example, heavy dust loading occurs at about 20,000 BP, near the height of the Wisconsinan glaciation, but drops off sharply at the beginning of the Holocene, to only 1/15 the previous value. The dropoff precedes the temperature change (Petit *et al*. 1990:56). Likewise, the Holocene value from the Camp Century core (Greenland), is only 1/12 the late glacial value (Thompson and Mosley-Thompson 1981). Recent computer modeling by Overpeck and others (1996), on the other hand, suggests that atmospheric dust actually caused episodic regional warming (over 5° C) of areas downwind from ice margins and may have triggered abrupt warming events. Depending on size and reflectivity, dust can both scatter and absorb sunlight, and it tends to warm the upper atmosphere, but cool dark surfaces (such as oceans or forests); the reverse is true over surfaces with high albedo (such as ice and sand sheets; Harrison *et al*. 2001:48). Heavy dust in polar regions has been attributed to increased aridity and less frequent washing out of surface dust by precipitation (Yung *et al*. 1996), greater windiness, and expansion of source areas (Harrison *et al*. 2001:58-59), but dust loading was spatially variable. Dust in the Greenland ice cores has been traced to east Asian source areas, so it does not bear directly on the question of North American aridity during the glacial period. During the Last Glacial Maximum, dust accumulation rates were highest at latitude 20-25° N in the Atlantic basin and at 30-50° N in the Pacific basin (Kohfeld and Harrison 2001:Fig. 10).

The Bermuda High

The Bermuda High is a persistent high-pressure area located in the Atlantic, off the eastern US seaboard. Expansion and/or southwestern movement tends to cause increased precipitation both on the western Gulf coastal plain (Keim 1997) and southern Plains (Forman *et al*. 1995:51, Figs. 9, 10) with anticyclonic advection of moisture from

the Gulf of Mexico. Contraction or northeast movement causes drought. Persistent episodes of expansion or southwesterly movement might cause clusters of heavy rainfall events that could show as flood-prone periods at archeologically-resolvable time scales, but the atmospheric mechanisms that might cause such long-term shifts in the position of the high are essentially unknown.

El Niño-Southern Oscillation (ENSO) Events

In normal years, the westward-moving Pacific trade winds pile up warm water in the western Pacific (about half a meter higher than in the eastern Pacific) and produce cold upwelling along the western coast of South America (about 8° C cooler). The warm western Pacific sends heat and moisture into the upper atmosphere. During El Niño events, this system breaks down: the trade winds weaken, warm water extends into the eastern Pacific, and upwelling diminishes. Pressure gradients along the equator (the Southern Oscillation, starting in October and occurring most commonly on a 6-year cycle; Burroughs 1992:49) diminish. The linked wind-water-pressure process is known as an El Niño-Southern Oscillation (ENSO) event. Although ENSO events originate far away in the tropical Pacific, they have profound effects on United States weather. During ENSO events, tropical Pacific storms spread farther eastward, strengthening the jetstream and displacing it southward. Manty (1993:xxxiii, Fig. 4.9) found that during El Niño winters from 1966 to 1989 the southern jetstream at the 250 millibar pressure level was intensified by 5-10 meters per second and displaced southward 200-285 km.

Warm western Pacific events like these (which occur every two to seven years) may be followed by *cool events* (referred to either as *La Niña* or *El Viejo*). Normal years are referred to as "neutral" events. During warm ENSO events, heavy rainfall occurs in

the Southwestern US and around the Gulf of Mexico in October, November, and December (Ropelewski and Halpert 1987:Fig. 21; Burroughs 1992:Fig. 5.8a; Cleaveland, Cook, and Stahle 1992) and major winter floods may occur in the Southwest (Ely, Enzel, and Cayan 1994). Warm Pacific sea surface temperatures are also correlated with heavy rainfall in Texas from November through March (Montroy 1997:552, Fig. 8; Manty 1993:62-63, 285; Mjelde *et al*. 1997:Fig. 1). In fact, the strongest ENSO effect in the eastern United States is found in Texas and other Gulf states (Cleaveland, Cook, and Stahle 1992:279). Warm events may also be associated with cooler than normal temperatures on the Texas Gulf coastal plain in the winter, spring, and summer (Green *et al*. 1997), although the temperature effect is less pronounced than the precipitation effect. At Corpus Christi, for example, over the period 1887-1950, winter temperatures averaged 13.8° C in *El Niño* and 15.7° C in *La Niña* years (Manty 1993:Table 2.5). In the southeastern US, there is about a 2° C difference between warm and cold event years (Diaz and Kiladis 1992:20) over land. Over the Gulf, sea surface temperature is about 0.7° C cooler and air temperature 1.4° C cooler during warm events (White and Downton 1991:Table 15.1). Cold or *La Niña* events tend to be associated with reduced rainfall (Montroy 1997:552; and below average tree growth in the year following an event, as shown by tree ring studies). This effect can be seen in 42 years of rainfall records at Yorktown, in the Berger Bluff catchment. Average rainfall for *El Niño* years runs about 14 cm higher than for *La Niña* years (Table 1.4). Warm events also tend to suppress hurricane formation in the Gulf; the frequency of hurricanes in a warm event year is about half that in a neutral year (O'Brien, Richards, and Davis 1996). This apparently happens because increased westerly wind shear decapitates tropical disturbances before they can form hurricanes (Gray and Sheaffer 1991:258-264).

Since *El Niño*-induced winter rainfall normally starts in October and may last through the following months into the next calendar year, half of the rainfall may fall in one calendar year, while the rest is reported in the next year's statistics. This tends to conceal the ENSO effect in annually compiled rainfall amounts. Hydrologists have long recognized this, even before the significance of ENSO events was understood, and as a result the hydrologists' "water year" starts on October 1 and extends to the following September 30. Table 1.4 might have been more representative had it been compiled using water years, but would have required too much manipulation of monthly data. Lagging the ENSO events by one year actually reduces the contrast between warm and cold years to about 6 cm of precipitation, suggesting the calendar year data used here are an adequate expression of the data.

El Niño Events: Mini-Analogs for Pleistocene Climates?

The reader will note that warm events have some of the key attributes (southward-displaced jetstream and enhanced winter rainfall, reduced summer temperatures, and lack of hurricane formation) that I have already identified for full-glacial climates in Texas. Can *El Niño* years be considered mini-analogs for Pleistocene climate in the eastern part of Texas? Future researchers should ponder this possibility. Stott and others (2002) propose that Late Pleistocene stadial conditions at high latitudes were correlated with *El Niño*-like climatic conditions in the western Pacific.

Another interesting characteristic of ENSO events is the tendency for the system to go from one extreme to the other in adjacent years (Diaz and Kiladis 1992:11). This means that heavy rainfall in an *El Niño* year may be followed by drought in a *La Niña* year, a very non-equable climatic regime that selects for hardiness in plants and animals.

In other words, ENSO-like climates should select for eurytopic species and against stenotopic species. *La Niña* years also tend to be associated with episodes of "false spring" (unseasonably warm winters followed by a hard spring freeze; Stahle 1990:177-189), which are also stressful for plants and animals (especially poikilotherms).

How old are ENSO-like climatic features? Did *El Niño* events occur at all in the Late Pleistocene? What about the early Holocene? Direct evidence must come either from the tropical Pacific or coastal South America. Proxy evidence of teleconnections might be found in other areas, but it might be hard to prove climatic effects elsewhere are ENSO-related. The evidence from coastal Peru is somewhat controversial (see comments in DeVries *et al*. 1997, Wells 1990). Martin *et al*. (1993) argue for intermittent ENSO-like events beginning at least 7000 BP, based on South American evidence. Based on debris-flow deposits with a lower infrared-stimulated thermoluminescence date of 38,200±4300 cal years BP and an upper radiocarbon date of 10,770±150 RCYBP (about 12,880 cal BP, and absent at about 5300-8400 cal BP), Keefer *et al*. (1998, 2003) argue for the presence of Late Pleistocene El Niño events at Quebrada Tacahuay, Peru (see also Moy *et al*. 2002; Rodó and Rodriguez-Arias 2004). The debris flows are thought to have been left by exceptionally severe events with a recurrence interval of “less than 2530 years” (Keefer *et al*. 2003:69); during the early Holocene, the maximum recurrence interval was 600 years. Anderson, Soutar, and Johnson (1992:430) also claim to recognize "*El Niño*-like" and "*La Niña*-like" conditions off the coast of California in the Late Pleistocene (also Heusser and Sirocko 1997, Bull, Kemp, and Weedon 2000; but see discussion in Cole *et al*. 1992:357). A lake core from Laguna Pallcacocha in southwestern Ecuador shows cyclic banding back to about 12,470±80 RCYBP, interpreted by Rodbell and others (1999) as ENSO evidence, but the banding is very

weak before about 6200 RCYBP, and occurred on about a 15-year cycle (Rodbell *et al*. 1999:519, Fig. 5), suggesting a weak ENSO system. Climate modeling suggests that *El Niño* may have been suppressed in the early Holocene by the intensified Asian monsoon, which increases upwelling and cooling in the central to eastern Pacific (Liu *et al*. 1999). In some cases, cyclic climatic behavior throughout the Quaternary, regardless of cycle length, has been attributed to the ENSO system – for example, stacked Wisconsinan-aged paleosols in Illinois have been examined for $\delta\ ^{13}C$, iron content, and color, revealing cycles with periodicities of 800-1000, 450-550, and 350-390 years that have been attributed to ENSO-like climate cycles (Wang, Follmer, and Chao-Li Liu 2000; Wang *et al*. 2003).

Tudhope and others (2001) see evidence of a weak ENSO system in cores through annually banded coral from Papua New Guinea, at various times during Pleistocene glacial periods. Thermal and circulation properties of the glacial-age atmosphere and oceans were so different from Holocene patterns that I find it difficult to envision a contemporary ENSO system existing in a Pleistocene environment, although Koutavas and others (2002) argue that increased equatorial seasonality during the Late Pleistocene (about 17,000-21,000 cal BP) favored the growth of *El Niño* events by weakening trade winds (although see Koutavas *et al*. 2002:Fig. 2, C). Note that they define *seasonality* as the difference between March and September insolation at the equator, whereas I define it here as the difference between December and June insolation at latitude N29° in Fig. 1.5, A. Even if ENSO events were present during the Pleistocene, it is not necessarily clear whether the effect on Texas weather would be the same as is seen today. Contemporary ENSO events affect Texas weather by displacing the jetstream, but in the late glacial period, the jetstream and the Intertropical Convergence

Zone were already displaced southward, so it is not clear whether glacial-aged ENSO events would increase (as in today's climate) or diminish winter rainfall.

Individual ENSO events (for example, a major winter flood generated by heavy warm-event rainfall) are plainly too short-lived to show up in the archeological record, but clusters of events within a span of, say, one or two centuries might appear, in the same way that I have suggested clusters of volcanic events might leave an imprint in the paleoenvironmental record (see Charles 1998). Without annually-resolved proxy data, however, demonstrating that these were due to ENSO patterning might be difficult.

INSOLATION

Astronomical forcing makes insolation (the amount of solar radiation received by the earth) vary over long periods. The eccentricity of the earth's orbit around the sun affects insolation on a 100,000-year cycle. Of more interest are changes in axial tilt (the 41,000-year cycle) and precession of the equinoxes (22,000-year cycle). The tilt of the earth's axis with respect to the sun, which is now 23.44°, determines the amount of seasonal contrast between summer and winter. Increased tilt means more radiation for polar regions (Imbrie and Imbrie 1986:Fig. 25). It chiefly affects high latitudes and is much less important at N29°, the approximate latitude of Berger Bluff. Precession of the equinoxes is much more important, especially in low latitudes (Imbrie and Imbrie 1986:107); it determines the seasonal distribution of the annual radiation budget. Today, winter begins when the earth is close to the sun, at one extreme of its elliptical orbit, but 11,000 calendar years ago (about 9870 radiocarbon years BP), winter began when the earth was much farther away from the sun, at the opposite end of the ellipse (Imbrie and

Imbrie 1986:73). Interaction between the precession effect and the axial tilt effect has produced complex patterns of insolation changes at different latitudes. As Dawson (1992:239) notes,

> A critical factor...was the seasonal temperature gradient between low and high latitudes — known as the insolation gradient....During periods when the insolation gradient from the equator to the pole was high, meridional (north-south) circulation would have been increased, thus providing a greater rate of delivery of snow-bearing precipitation to high latitudes. By contrast, low meridional temperature gradients would have been associated with oscillatory jet stream flow, the more frequent development of blocking high pressure systems in the middle latitudes and a decrease in the rate of supply of moisture to high latitudes.

In 1978, Andre Berger published a FORTRAN computer program to calculate this complex pattern of past insolation rates for given latitudes of the earth's surface. This program was later adapted by Nicholas Pisias, and eventually rewritten in TurboPascal by Owen K. Davis of the University of Arizona. This version of the program (INSOLATN.EXE) is available for downloading on the World Wide Web, and I have used it to calculate the insolation values displayed here in Langleys/day.

Using values produced by Davis's program, I have produced two series of plots. The first series (Figs. 1.2-1.4) shows insolation changes from the full-glacial (18,000 radiocarbon years BP) to the early Holocene (7000 BP) for certain selected months; the period of chief interest for the present study, 8500-11,000 BP, is marked by a screen pattern, and the modern insolation value is also shown for comparison. The reader should note that while Davis's program is keyed to calendar years, I have chosen to display the results on the distorted radiocarbon time scale, since that is the standard chronological scale for this study. In order to do that, I have used CALIB 3.03 to work backwards from calendar years to radiocarbon years (the difference between these scales will be discussed in more detail in the next chapter). In the first series of figures, I show changes in annual

insolation (Fig. 1.2, *A*), followed by insolation for January (at the height of winter), May (the second-wettest month of the year), July and August (normally dry months, when Gulf sea surface temperature rises), and September (the wettest month and the chief hurricane month at present).

Fig. 1.2, *A*, shows that annual insolation was actually above present-day levels throughout the end of the Pleistocene and during the early Holocene, peaking at 10,000 radiocarbon years BP, at about 101% of the modern value (from a percentage viewpoint, the changes shown on these plots are not large) and declining thereafter. January insolation, on the other hand (Fig. 1.2, *B*) declined below contemporary levels by 15,000 BP and reached a minimum by 9000 BP. May insolation (Fig. 1.3, *A*), on the other hand, peaked by 11,500 BP and declined thereafter. July and August insolation were near modern values in the late glacial, increasing steadily throughout the 8500-11,000 BP time

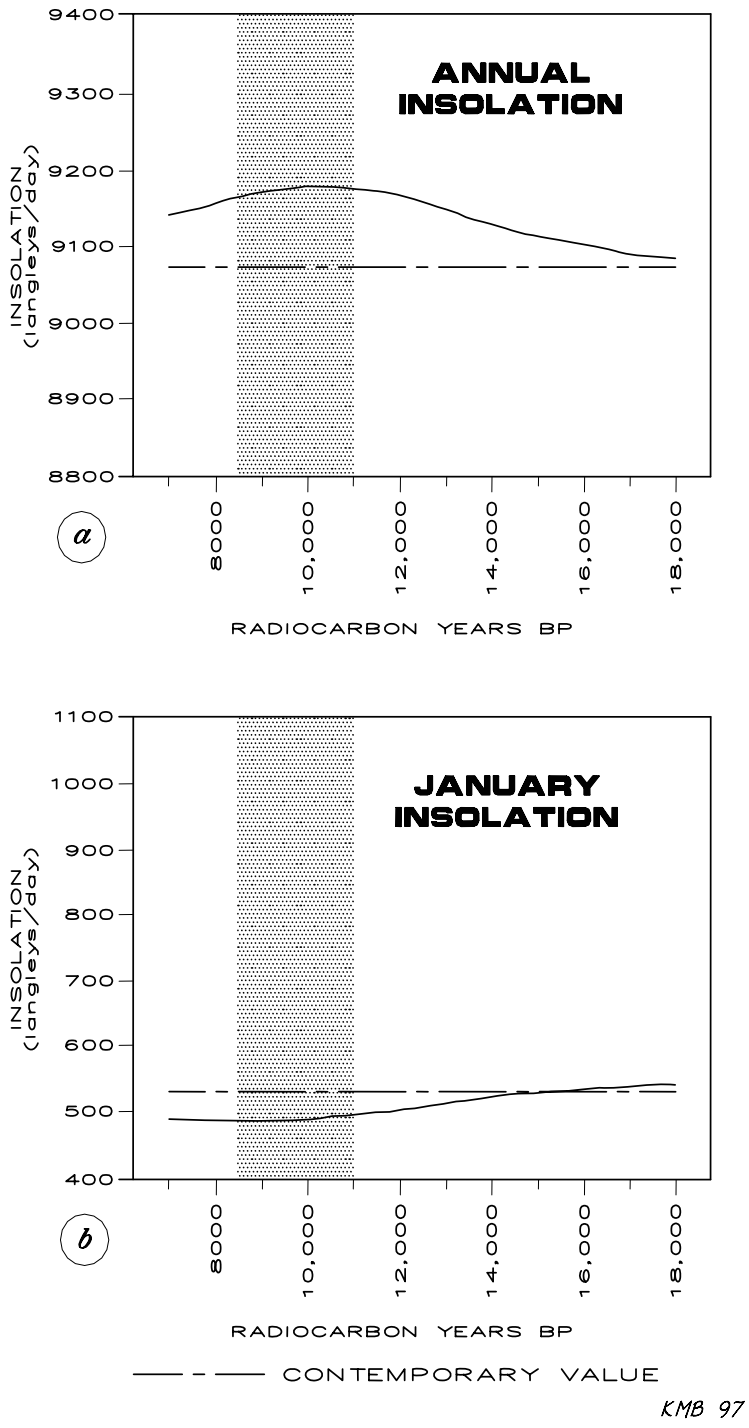


Figure 1.2. *A,* Annual Insolation at 7500-18,000 Years BP. Computed for lat N29° using INSOLATN, showing insolation in langleys/day over a complete year. *B,* January Insolation. Period represented by Berger Bluff bench is shaded.

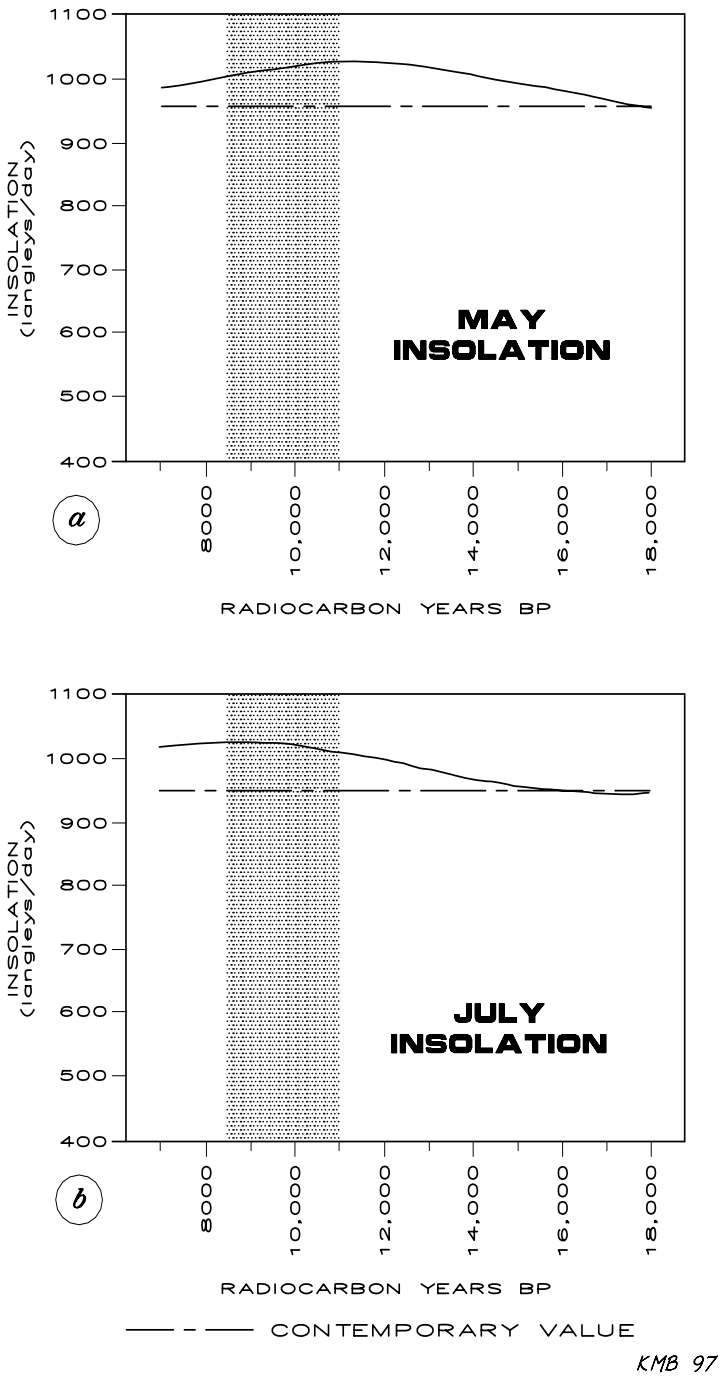


Figure 1.3. *A*, May Insolation at 7500-18,000 Radiocarbon Years BP. Computed for lat N29˚ using INSOLATN, showing insolation in langleys/day during May. *B*, July Insolation for Same Period. Period represented by Berger Bluff is shaded.

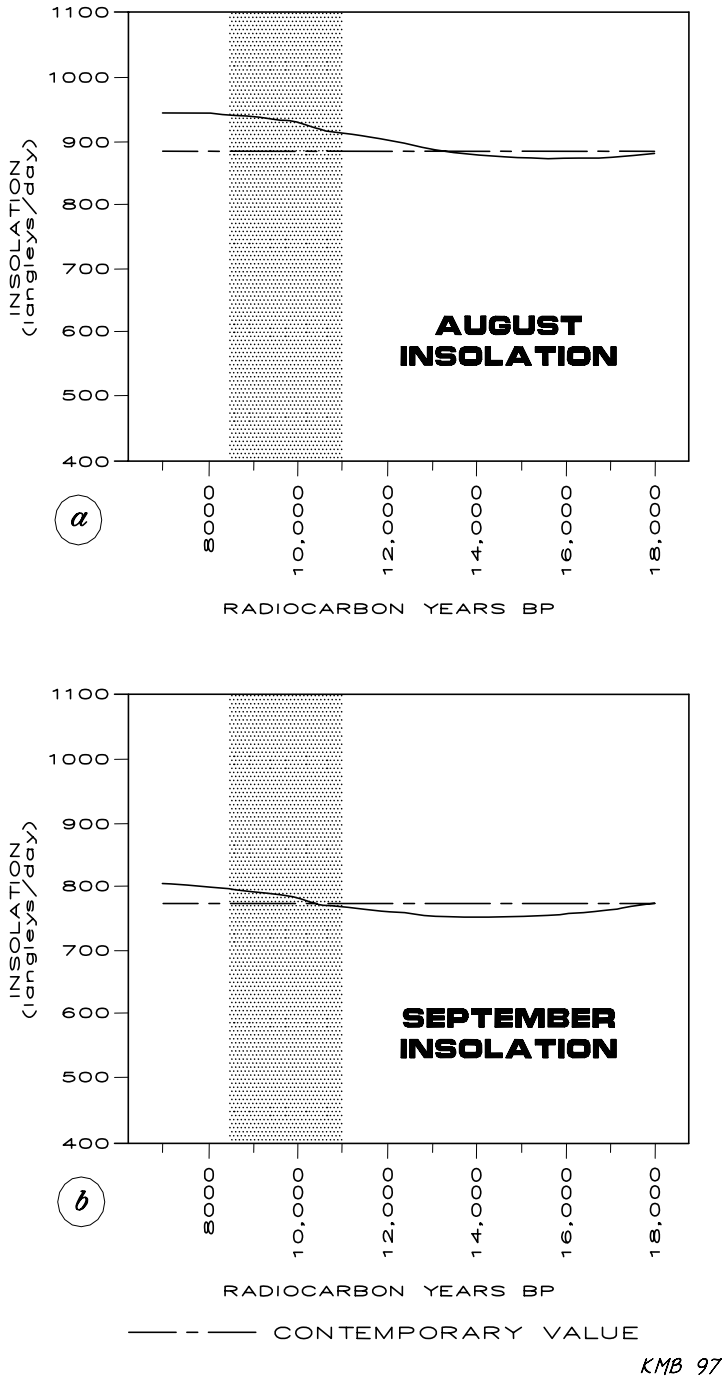


Figure 1.4. *A*, August Insolation at 7500-18,000 Radiocarbon Years BP. Computed for lat N29° using INSOLATN; insolation in langleys/day during August. *B*, September Insolation, Same Period. Period Represented by Berger Bluff bench is shaded.

span (Figs. 1.3, *B*, 1.4, *A*). July insolation peaked by 9000 BP, but August insolation continued to rise until 7000 BP. September insolation (Fig. 1.4, *B*) was near contemporary levels at 10,500 BP, then rose somewhat until at least 7000 BP. Fig. 1.5, *A*, shows insolation "seasonality," or the difference in insolation between the month with the most insolation (June in every case) and that with the least (December in every case). The pattern is very similar to that for the total annual insolation, with insolation "seasonality" about 100 langleys/day above modern levels throughout the period when the bench deposits were forming, and peaking at 10,000 radiocarbon years BP.

Perhaps the most important thing to note about this series of figures is that for the months of July, August, and September, the critical months when heating of the Gulf can generate hurricanes, solar radiation was steadily increasing to levels above contemporary values throughout the period when the bench deposits were forming at Berger Bluff.

The second series of plots (Figs. 1.6-1.10) consists of circular graphs designed to show the seasonal distribution of insolation at 7000, 8500, 10,000, 11,000, and 18,000 radiocarbon years BP. All these plots are off-center because most insolation is received in the summer months. The plot for 10,000 BP is most off-center, that for 18,000 BP the least because these two periods have, respectively, the most and least seasonal contrast. The reader will also note that none of these plots appear greatly different from each other, especially at the scale shown here, because the differences involved are relatively small percentages of total annual insolation.

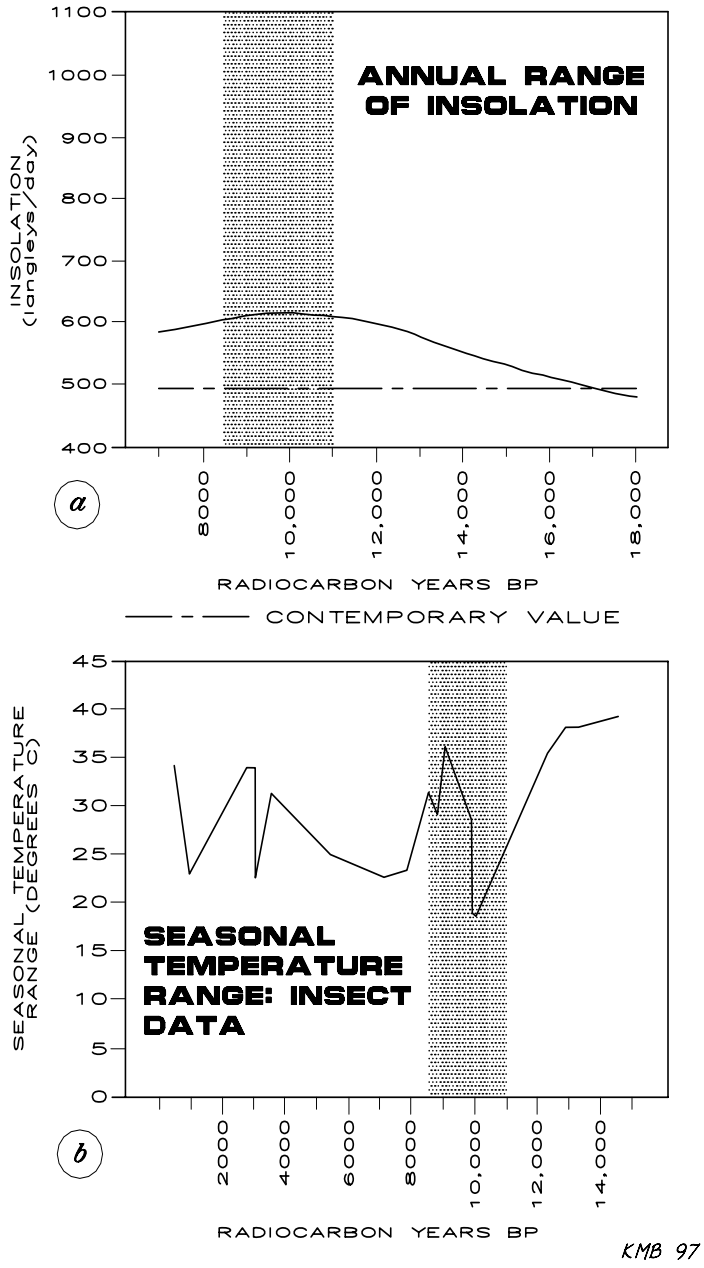


Figure 1.5. *A*, Annual Range of Insolation at 7500-18,000 Radiocarbon Years BP. Computed for lat N29° using INSOLATN, showing difference between December and June values. *B*, Seasonal Temperature Range, Rocky Mountain Fossil Insect Data. Difference between estimated January and July temperature, 14,000 RCYBP-present (data from Elias 1996:Table 1). Period represented by Berger Bluff bench is shaded.

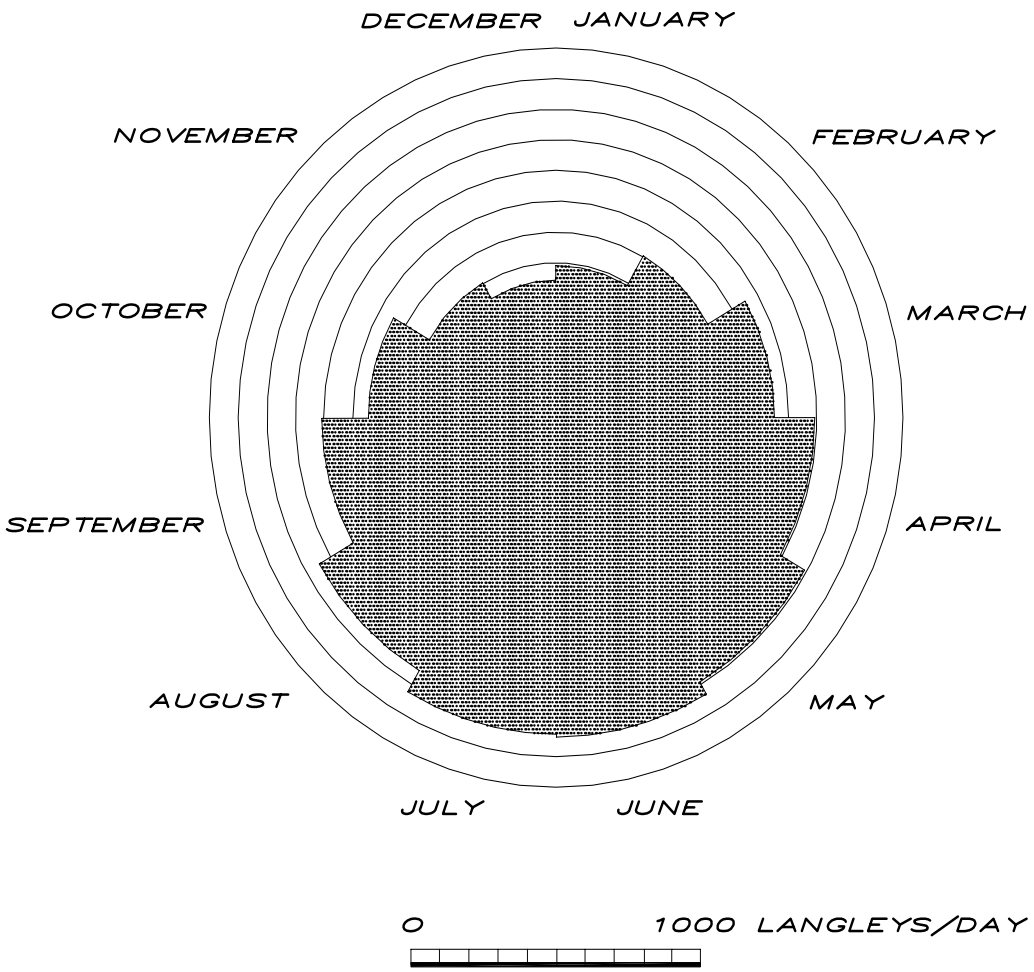


Figure 1.6. Monthly Insolation Values at 7000 Radiocarbon Years BP. Computed for lat N29° using INSOLATN. Next four circular graphs (Figs. 1.7-1.0) follow the same format. Plotted at this scale, shifts in seasonal distribution do not look pronounced.

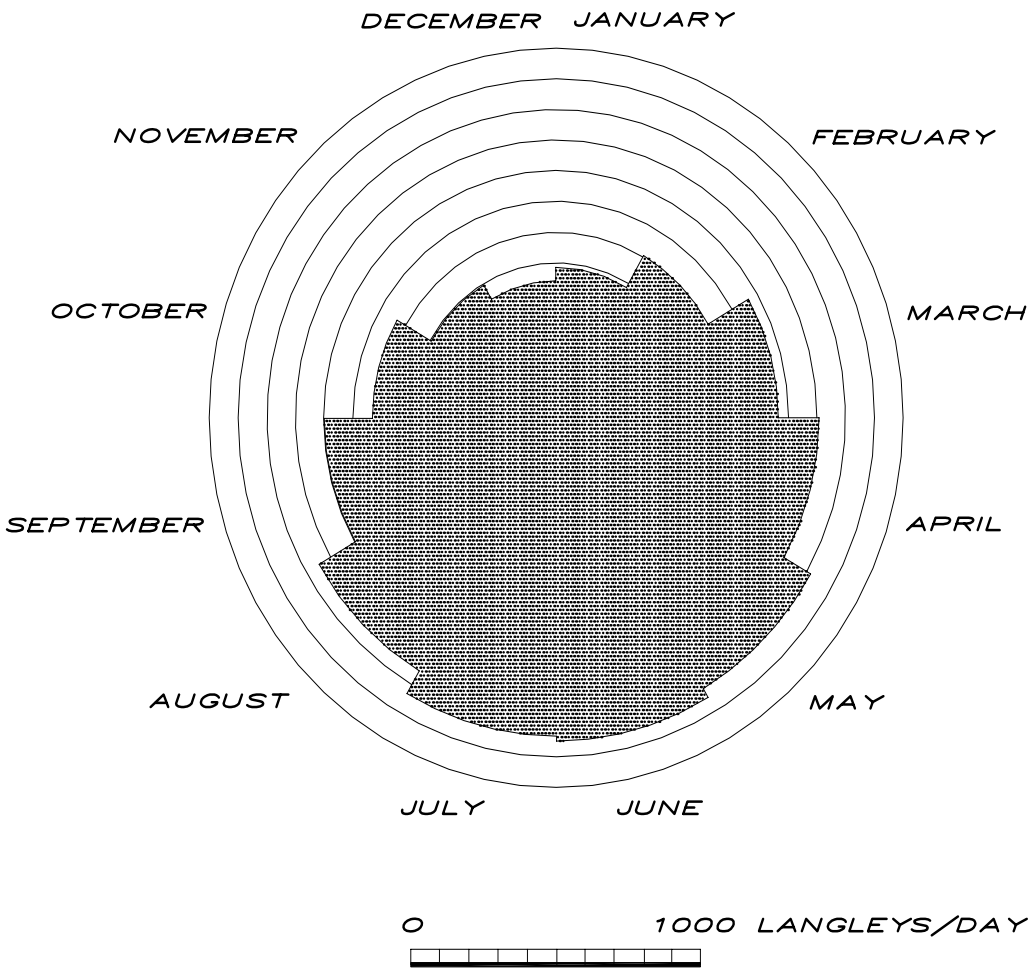


Figure 1.7. Monthly Insolation Values at 8500 Radiocarbon Years BP. Computed for lat N29° using INSOLATN, showing the seasonal distribution of insolation at the end of the bench stratigraphic sequence.

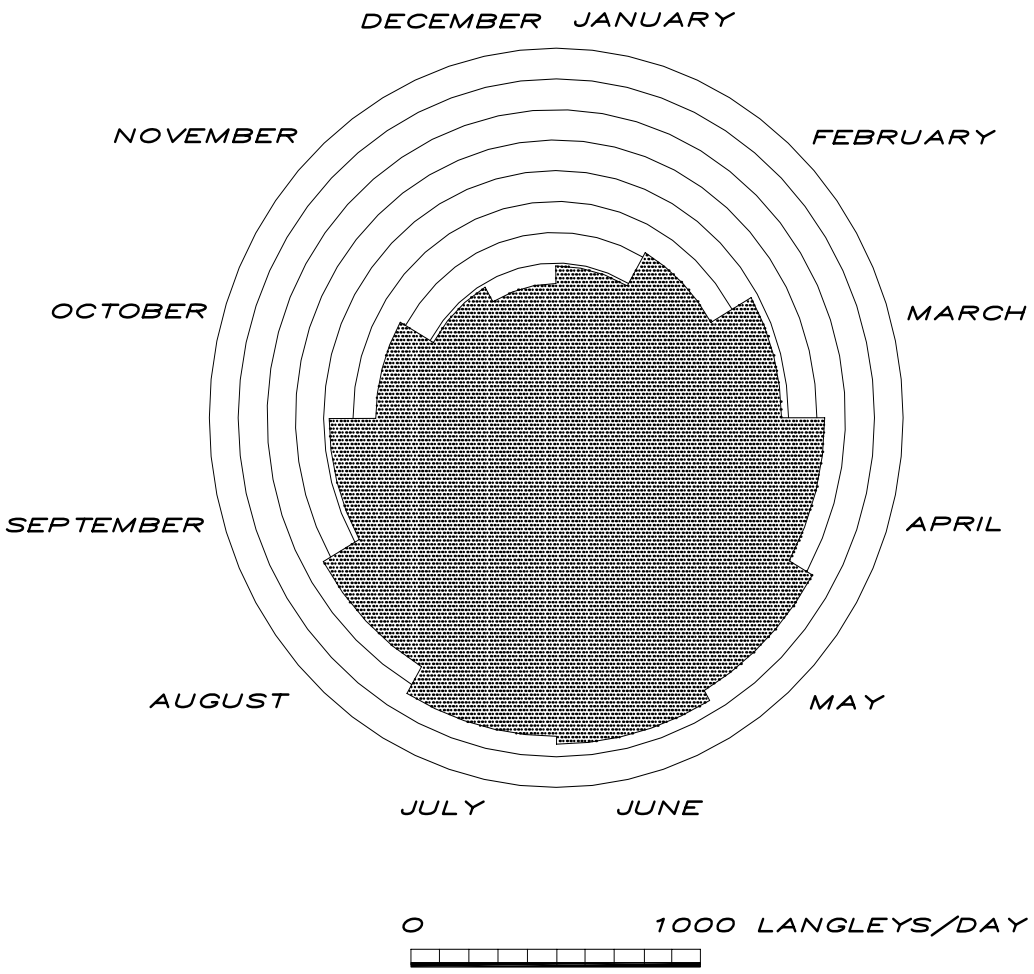


Figure 1.8. Monthly Insolation Values at 10,000 Radiocarbon Years BP. Computed for lat N29° using INSOLATN, showing the seasonal distribution of insolation about midway in the bench stratigraphic sequence.

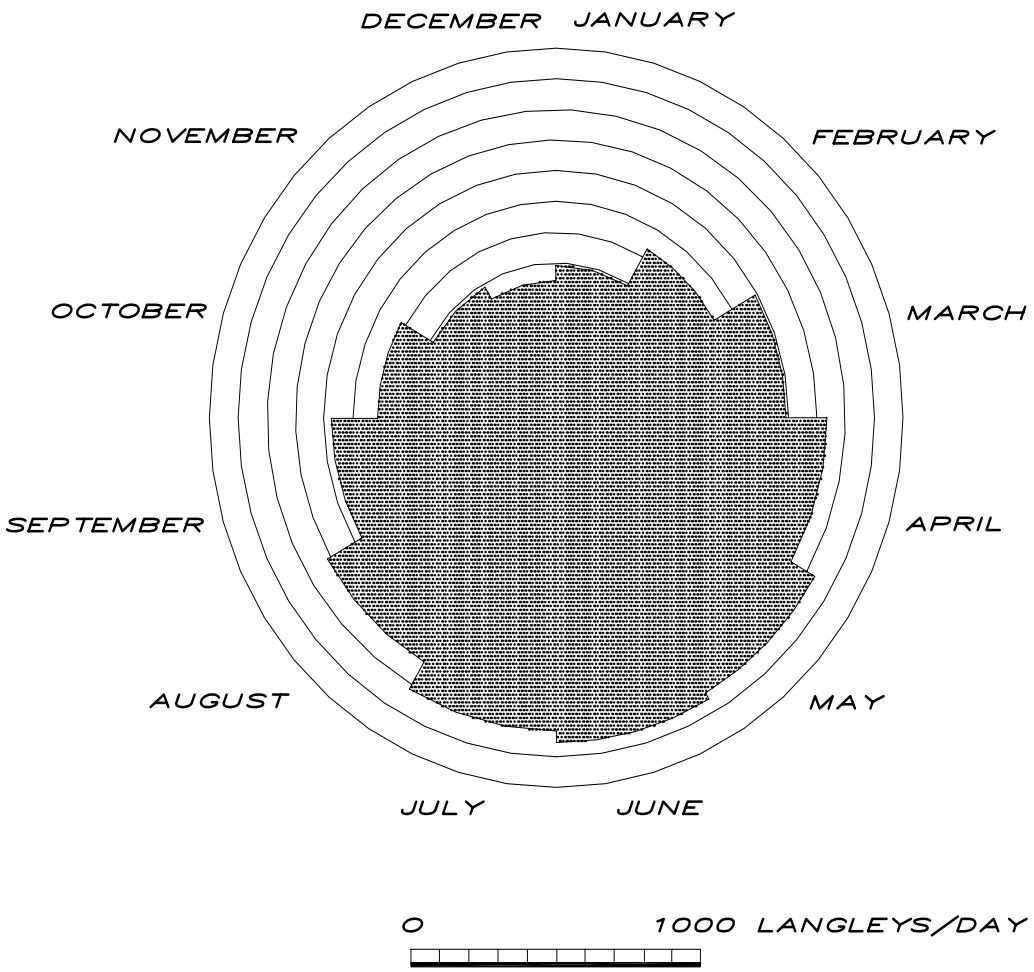


Figure 1.9. Monthly Insolation Values at 11,000 Radiocarbon Years BP. Computed for lat N29° using INSOLATN, showing the seasonal distribution of insolation at the beginning of the bench stratigraphic sequence.

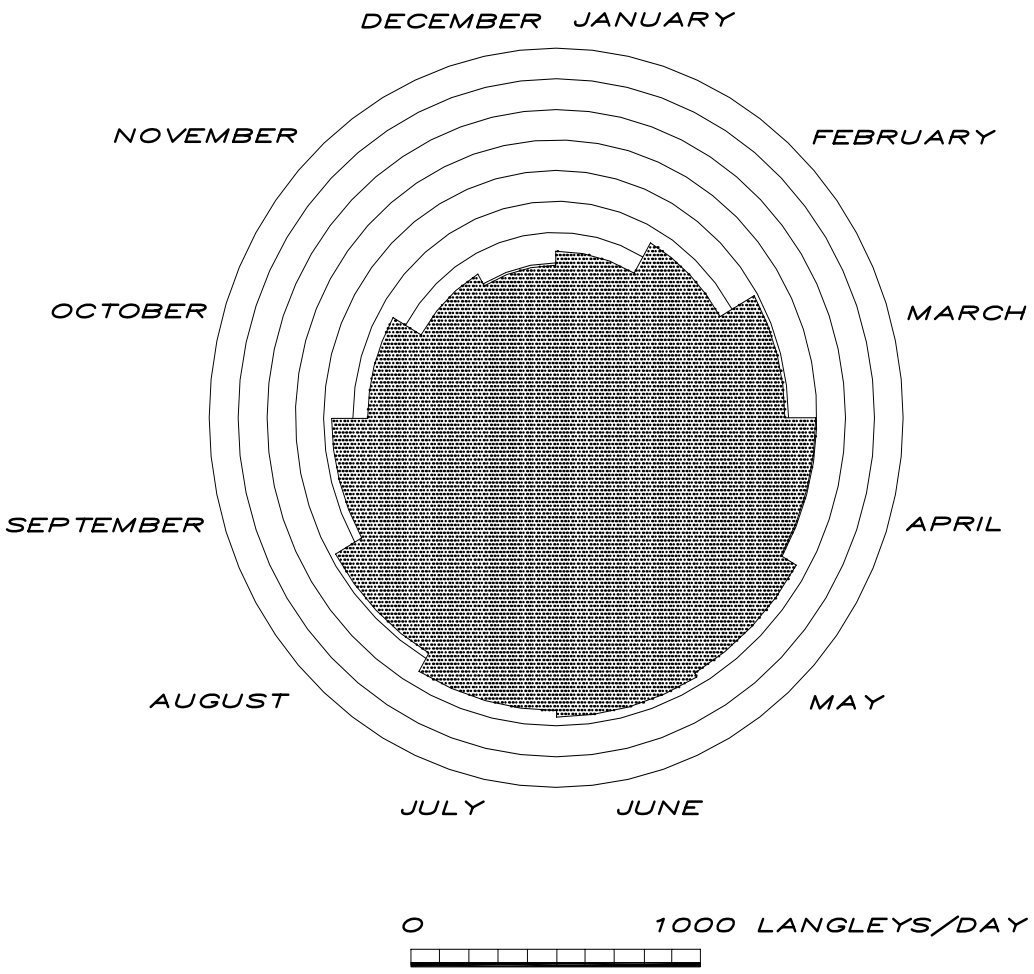


Figure 1.10. Monthly Insolation Values at 18,000 Radiocarbon Years BP. Computed for lat N29° using INSOLATN, showing the seasonal distribution of insolation at the full glacial maximum.

SEASONALITY

There seems to be a consensus among Quaternary paleoecologists (or at least, among North American practitioners) that Pleistocene climates were more *equable* (less subject to seasonal extremes) than Holocene ones, which are viewed as much more *seasonal* (Martin and Martin 1987). This is probably true, but to some extent it is another example of received wisdom. Demonstrating the seasonal range of climate requires proxy data with a resolution of at least six months or finer, and there are few kinds of data that can reach back into the Pleistocene with subannual precision. Finely laminated varves that probably represent daily events (and can be counted to determine the length of the late Pleistocene summer) have been found in Sweden (Ringberg 1984), but proxies with this kind of resolution are rare, scattered, and discontinuous. Tree rings (width data or deuterium content) can furnish subannual precision, but there are no continuous records reaching back into the full glacial. Oxygen isotope variations in laminated mammoth tusks (Koch, Fisher, and Dettman 1989) and dentin increment analysis in mammoth tusks and teeth give us some idea of the seasonal amplitude of such measurements, but we have nothing for comparison, since continental mammoths are extinct. The mid-Holocene mammoths from Wrangel Island could be studied, but may not help us understand continental climatic history.

"Seasonality" is usually ill-defined by archeologists and Quaternary paleoecologists. Presumably it could mean seasonal contrast in temperature, insolation, precipitation, evaporation, windiness (Zielinski and Merson 1997:558), or some other factor, but seasonal temperature changes are probably what most paleoecologists envision. Lambeck, Esat and Potter (2002:200) observe that “Growth of large ice sheets

requires warm temperatures during winters to enhance moisture transport to high latitudes, and cool temperatures during summers to prevent melting of snow." From this, we expect that the last glacial period would have featured summer temperatures much lower than present, but winter temperatures similar to, or perhaps even higher than present temperatures. Fossil insects are one of the few kinds of proxy data that can capture both winter and summer temperatures. Most other proxies (for example, noble gases, altitude lapse rates, or carbon isotopes) record only mean annual temperature or summer maximum temperatures.

Fig. 1.5, *B*, is a plot of the difference between mean January and July temperatures derived from Elias's Rocky Mountain insect data (Elias 1996:Table 1). It shows that, contrary to expectations, the reconstructed mean annual temperature range actually declines at the onset of the Holocene, rather than increasing, and mid-Holocene temperatures were actually more equable as well. Unfortunately the data are not old enough to show what was happening in the full glacial; the curve starts at 14,500 radiocarbon years BP, during the late glacial warming period. What signals increased "seasonality?" Is it an expansion in the annual range of temperature between summer and winter, as in the peaks seen at 2965 and 9000 BP (Fig. 1.5, *B*, Fig. 1.11), or is it a drop in the winter minimum temperature, such as those seen at 2965 BP, 9000 BP, and 12,194 BP (Elias 1996:Fig. 2)? Put another way, what are the most crucial limiting factors for human populations or the biota on which they were dependent? Is it the ability to survive winter cold or is it the ability to survive summer heat that defines an organism's range? Or both?

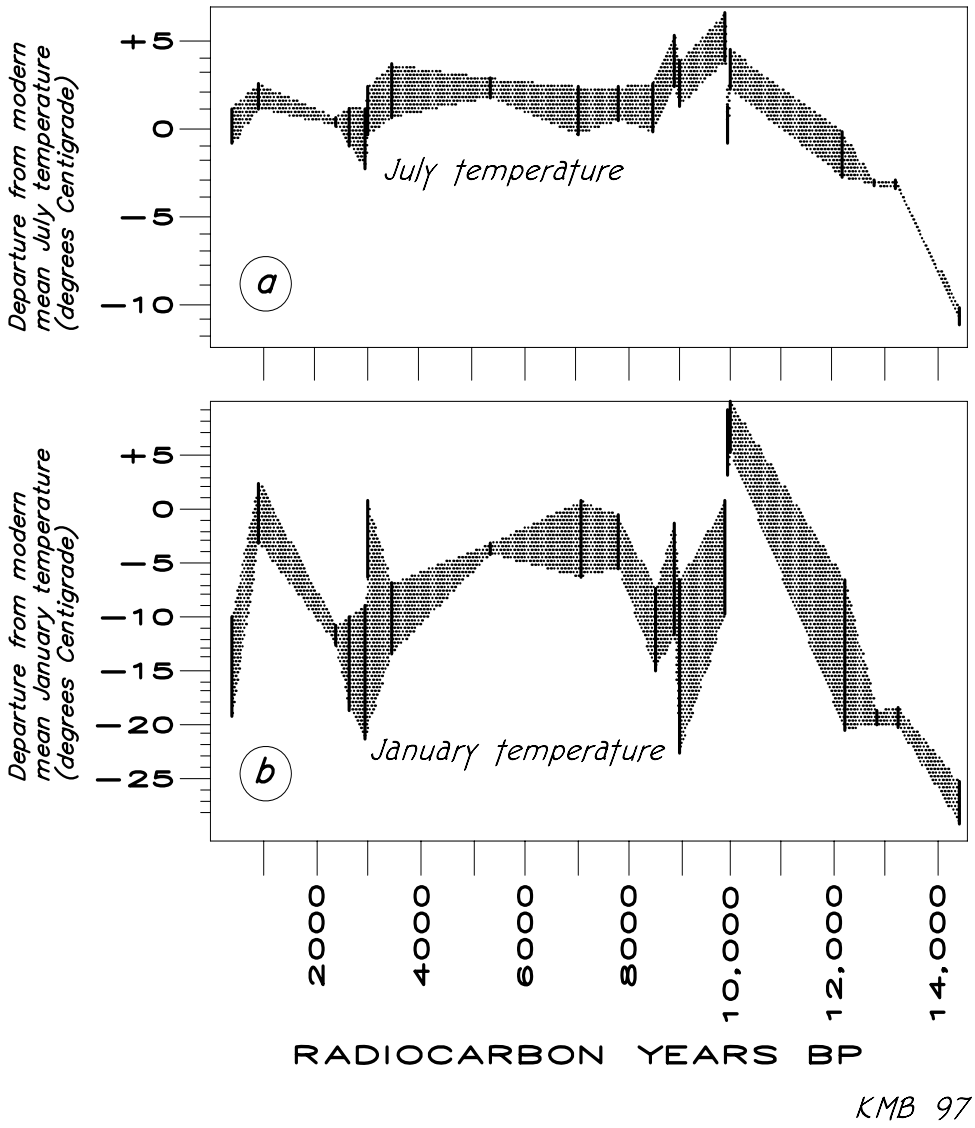


Figure 1.11. Temperature Estimates from Rocky Mountain Fossil Insect Data. A, departure from modern July temperature. B, departure from modern January temperature. Note winter temperatures fluctuate more radically at these high-altitude sites; also note excursion at 10,000 BP. Vertical bars represent mutual climatic range of beetle species (adapted from Elias 1996:Fig. 2).

The insect data show that it is *chiefly the winter minimum temperatures that fluctuate* in the late Quaternary (Fig. 1.11); the summer maxima are much less variable. We might suppose that this is in large part due to the relatively high elevation of Elias's sites (most over 2700 meters), but the same pattern can be seen in the British insects. And insect data from the Canadian maritime provinces show the same thing – winter temperature departures are greater than summer departures at 10,600-12,600 RCYBP, and the winter temperatures show greater fluctuation over time than the summer temperatures (Miller and Elias 2000:Fig. 2). This would seem to contradict the model for ice sheet growth sketched above, except that the insect data begin around 13,000-14,000 RCYBP, after the glacial maximum, when climate warming had already started. Are these insect-based temperature patterns unique to the particular type of proxy data, or are they simply not old enough to capture Full Glacial climates?

The Berger-Davis insolation model cannot show the annual temperature range, but it can show the annual range in insolation values, and here a picture emerges that differs somewhat from the insect data. The annual range in insolation values (here always the difference between the December and June values), as we have seen, rose above the modern level by about 17,000 BP and peaked at 10,000 BP. Curiously, though, most of this increased insolation "seasonality" comes from increased solar radiation during the summer months. The change in winter insolation (Fig. 1.2, *B*) is much less pronounced. In other words, the astronomical model seems to say that seasonality increases at the onset of the Holocene, and summer radiation is mostly responsible. The cordilleran insects, on the other hand, seem to say that seasonality drops sharply at the onset of the Holocene, then peaks again at 9000 BP, then drops again, and that winter temperatures are mostly responsible. What accounts for the discrepancy between these two views?

Altitude and latitude may be relevant. Continentality is reduced in mountainous areas (Fig. 1.1) because summer highs are restricted. And nearly all of Elias's sites are north of N40° latitude, where changes in axial tilt would have been somewhat more important than at N29° latitude. In other words, location may have had a significant effect on "seasonality" changes during the Pleistocene-Holocene transition, and the pattern of change at Berger Bluff may have been different from that in the cordilleran area. Some of the packrat midden data support this possibility. Early Holocene packrat midden data from northwestern Colorado, assayed at 9870 RCYBP, show January temperatures 1 to 3° C below modern and July temperatures 3 to 10° C below modern (Sharpe 2002:Table 1). Van Devender (1990b:155) estimates a Late Wisconsinan temperature departure of about 3.6 to 5.0° C below modern for January and 8.4° C below modern for July at Picacho Peak, Arizona. Other reconstructions using packrat midden data from the Sonoran Desert estimate departures of 5° C for December-January and 3° C for July-August (Arundel 2002:Fig. 3).

DIFFERING VIEWS OF CLIMATE CHANGE: WHY THE DISCREPANCY?

In this first chapter we have had the opportunity to see how astronomically oriented climate modelers, paleobotanists, and paleontologists have viewed late Quaternary climate change. The computer models and the empirical data reveal rather different views. Nothing in the computer models can predict the sometimes dramatic and abrupt periodicity of the empirical data, at least not on an archeological scale. And among the empiricists, there is a spectrum of opinions. The palynologists are most likely to agree with the modelers that climates wax and wane smoothly over thousand-year increments. The paleontologists and archeozoologists (especially those working in the northern Plains

under the influence of Wendland and Bryson's climatic framework) are much more likely to see episodic change in their data, and among the fauna, it is the insects recovered from sediments or packrat middens that are most likely to reveal abrupt, episodic change.

What accounts for the discrepancy between the Bryant-Shafer model of gradual climatic transition at the onset of the Holocene and the newer picture of sometimes abrupt, episodic, and cyclic change that has emerged from the ice core, subfossil insect, and other new empirical data? I would argue that the willingness of Quaternary scientists to recognize abrupt, short-term episodic, or cyclic climatic change in their data depends on the *climatic sensitivity* or "response time" of their data, and that the response time depends in very large part on the lifespan (or age at reproduction) of the organism. Highly mobile organisms with short lifespans, like insects, are likely to respond much more rapidly to climate change than sessile, long-lived organisms like pollen-producing trees. Table 1.2 (condensed and modified from Williams 1981) illustrates this. Pollen-producing forest trees may often lag climatic changes by 1000-2000 years. Referring to postglacial dispersal of beech and hemlock into Michigan, Davis (1986:278) remarks

> Although expansion apparently could not keep up with climatic change, it still was rapid (100 to 400 m per year) relative to expectations of ecologists....Note, however, that 100 m per year is two orders of magnitude slower than the expansion rate of cotton rats in the course of the twentieth century....

Table 1.2. Response Time of Different Organisms to Climatic Change (condensed and modified from Williams 1981:Table 1).

Group	Immigration rate	Comments
Ostracoda	Immediate	Rapidly produced, easily dispersed, resistant eggs
Terrestrial insects	Rapid	Rapid reproduction, high mobility
Aquatic plants	Rapid	Rapidly produced and dispersed seeds, no maturing of soil needed
Aquatic insects	Fairly rapid	Rapid reproduction, high mobility
Small terrestrial plants	Slow but variable	Can depend on microclimate
Mollusca	Faster than trees	Few have lifespans > one year
Trees	Lags of 150 to 1000-2000 yr after suitable climate; migration rates 100-500 meters/yr	Slow to mature and reproduce, dependent on soil conditions
Mammals	Same as or following terrestrial plants	Herbivores, carnivores
Diatoms	Usually slower than terrestrial plants, but variable	Need silica leached from soil

Elsewhere, with Daniel Botkin, she observes that

> When climatic change occurs, adult perennial plants continue to survive, but do not reproduce successfully. Young plants of other species, better adapted to the new climatic regime, enter the community gradually, and existing plants are replaced as they die by invading species (Davis and Botkin 1985:336).

> Species abundances are not always in equilibrium with climate...biotic interactions can have a strong effect on climatic response and can obscure and delay the response...the pollen record in sediments, even if it records the vegetation perfectly, cannot resolve climatic changes more closely than within a century or two...The pollen record cannot distinguish between larger, short-lived changes and smaller changes of longer duration (Davis and Botkin 1985:338).

Webb (1986), on the other hand, maintains that delayed response of some pollen-producing species may be due to individualistic response of the species to particular climatic variables. In any case, in regions where both insect faunas and pollen assemblages have been thoroughly studied (Elias 1994:80-89), or better yet, where both have been studied at the same site (Berglund *et al*. 1984), the pollen data generally lag anywhere from 300 years to possibly as much as millennia behind the insects in responding to rapid climate changes. Of course, the insects respond mostly to temperature, while vegetation may be responsive to precipitation, temperature, growing season length, or other variables. Plants probably integrate more kinds of environmental variables than insects; this certainly makes them informative, but not necessarily responsive to abrupt change. In the Rocky Mountain region, Davis (1989:625) maintains that high-altitude pollen sites, where moisture is abundant, mostly document the Pleistocene-Holocene temperature change, while for low-elevation sites, it is moisture that is limiting. This might also explain some of the discrepancy between the insect and pollen records. In any case there are a number of fairly well documented millennial-scale cases of "vegetational inertia" in the paleoenvironmental literature (Cole 1985a, b; Markgraf 1985). Williams and others (2002) have used a novel method to study vegetation response in the North Atlantic region. Instead of simply looking at pollen counts from single taxa, they used core data from 11 European and North American lakes (all north of 45° N latitude), performed a principal components analysis of all the pollen counts from each lake, then computed the downcore correlation between the PCA factor

scores and two climate proxies ($\delta\ ^{18}O$ and chironomid-based temperature estimates) and performed a cross-correlation analysis to measure the lags of entire vegetation communities behind the climate proxies. For these sites, in which the individual sample resolution ranges from 16 to 93 years, some vegetation lags are about 400 years, but many are 200 years or less (Williams *et al*. 2002:Fig. 1). This may suggest part of the vegetational inertia documented in the older literature is simply the result of poor sampling resolution (extracting samples from cores at 20 cm intervals, perhaps, instead of 1 cm intervals).

At the same time, if we examine the distribution of vegetation at smaller scales (smaller than *biomes*, *provinces*, or *associations*), perhaps at the level of individual habitats, we may find examples of abrupt vegetational changes in particular habitats as a product of geomorphic change. The bench deposits at Berger Bluff probably furnish an example of this kind of change. Shelford (1932:Table 1) long ago defined a biome as covering about a million square miles, an association about 100,000 square miles, giving some idea of the scale involved. Palynological sites sample areas that are smaller than an association, but commonly larger than an individual habitat (usually various habitats are represented), making them less sensitive to geomorphically-driven habitat deletion. If vegetation at this spatial scale ("palynological scale") tends to show inertia in the face of abrupt climate change, can we conclude that Paleoindians had no need to adapt to vegetational change at the onset of the Holocene? Probably not, because individual habitats may still have changed drastically, even when inset into a larger matrix (biome, province, or association) stubbornly displaying Cole's "vegetational inertia."

I should also note that of the organisms listed in Table 1.2, the last three (pollen-producing trees, mammals, and diatoms), although perhaps the least responsive, are some of the environmental indicators most commonly recovered from archeological sites. Ostracods and insects would probably be more responsive climatic proxies, but are not recovered from archeological sites very often. This table also conceals a great deal of significant variation (r-selected and K-selected mammals vary greatly in lifespan).

A MODEL FOR CLIMATE CHANGE

The discussion to this point can be summarized in the form of a very general model for climate change:

1. As the GRIP and GISP2 ice cores show, past climates may have changed abruptly (i.e., in a few years), especially at the Pleistocene-Holocene transition;

2. Climate change may be cyclical. The cycles occur at many different superimposed frequencies and amplitudes. Many are either too long or too short to appear in the archeological record, but others may be occur at scales consistent with archeological resolution;

3. The magnitude of temperature change at the onset of the Holocene in lower mid-latitudes is unknown in any detail (except for a few estimates from insect and other data); it is likely to have been less drastic than in boreal areas. In any case, winter and summer temperature trends may have been largely independent; the insect data suggest the change in winter temperature is likely to have been greater than the change

in summer temperature, while insolation modeling and some of the packrat midden data suggest the opposite;

4. Likewise, the rapidity of temperature change at the onset of the Holocene in lower mid-latitudes is essentially unknown; it is likely to have been less rapid than in boreal areas;

5. Throughout the transition from the terminal Pleistocene into the early Holocene, total annual insolation at N29° was above present levels, late summer (hurricane season) insolation was above present levels and increased steadily throughout the period, and winter insolation was below present levels. The seasonal contrast in insolation was well above present levels, peaking at 10,000 BP;

6. In lower mid-latitudes, precipitation change is likely to have been more significant than temperature change, especially in maritime areas;

7. Long-term, gradual changes in precipitation were driven by northward migration of the jetstream in response to wasting of the Laurentide ice sheet, and possibly by a shift from zonal to meridional circulation;

8. The Pleistocene-Holocene transition is thought to have occurred near the end of a shift from winter-enhanced to summer-enhanced rainfall and from Pacific-derived moisture to moisture derived from the Gulf of Mexico;

9. Shorter term or episodic changes in precipitation, such as Haynes's "Clovis drought," or abrupt shifts in $\delta\ ^{13}C$ detected in soil/sediment humate samples, remain unexplained

for the time being. Causes such as clustered volcanic events or clusters of ENSO events cannot yet be ruled out;

10. ENSO events, whenever they began, should select for eurytopic biota and against stenotopic biota;

11. Maritime areas should have experienced less abrupt and less severe climatic change, except where maritime tropical storms are concerned;

12. Climate change may be regional, with opposing trends (antiphasing) in adjacent regions;

13. Because of bioturbation and time-averaging, abrupt climate changes (on the scale of a few years, as revealed in the polar ice cores) are not likely to be detectable in archeological sites, even though abrupt changes may have had major impacts on human populations;

14. As paleoenvironmental data sites, networks of archeological sites are perhaps best suited to revealing spatial patterns of precipitation changes.

SUMMARY

New data and analytical methods show that the conventional view of Pleistocene climates evolving into Holocene climates so imperceptibly as to remained unnoticed by human populations is simply wrong, at least for northern latitudes. How abrupt the

transition might have been in Texas, especially in areas that, like Berger Bluff, are buffered by proximity to the Gulf of Mexico is still unclear. In some of the chapters to come, I hope to demonstrate *that threshold effects* can cause abrupt habitat deletion or reorganization, even in areas where the climate itself shows substantial maritime buffering.

Glacial-age and Holocene climates in Texas have differed in several important respects. In the full glacial, winter rainfall was probably more prevalent due to the displaced jetstream and moisture derived from the Pacific was probably more significant than now. The May-September bimodal rainfall pattern was probably reduced or lacking, with summer rainfall somewhat below contemporary levels. A greater proportion of rainfall in the cool season, when evaporation rates are much lower, probably meant that soil moisture levels were higher, and there may have been a much higher proportion of cool-season grasses in ground cover. Grasses with the C_3 photosynthetic pathway and carbon isotope values of -23 to -32 ‰ may have been more abundant. The onset of rainfall patterns driven by the El Niño-Southern Oscillation system meant the beginning of dramatic flipflops characterized by heavy winter rainfall in some years followed by drought the next year, a pattern that would select for euroky (environmental hardiness) in various kinds of biota and lead to extirpation of stenotopic taxa, and it is probably just this kind of transition that led to the disappearance of the "disharmonious faunas" thought to typify the Pleistocene.

Violent floods were probably uncommon in glacial-age drainage basins because the heat-driven, monsoon-like mechanisms for concentrating enormous amounts of precipitation in localized areas over short periods of time did not yet exist. As glacial

meltwater from the Laurentide ice sheet dissipated in the early Holocene, the Gulf warmed until enough heat energy was present to sustain hurricanes. By 8000-9000 BP an insolation maximum had arrived, maximizing the contrast between land and sea heating and allowing monsoon conditions to develop. The ENSO system would suppress hurricanes, but only in warm event years. The severe northers that characterize contemporary Texas winter weather also probably appeared for the first time in the early Holocene, perhaps around 8000 BP, as the Laurentide ice sheet waned.

Now that some of the key features of global climate during the transition to the Holocene have been reviewed, I will present an introduction to the study area — Berger Bluff and the drainage basin lying upstream from it.

BERGER BLUFF

Berger Bluff is a high, sandy, northeast-facing bluff that overlooks Coleto Creek at the eastern edge of Goliad County. Victoria County lies on the other side of the creek, and the city of Victoria is about 15.5 kilometers to the east. From the blufftop, the creek seems timeless. Heavy mist often hangs low over the creek bottom until late in the morning, when the sun breaks through to glance off the clear water and whiten the dew-soaked sand. Raucous kildeer ply the sedges and ragweed brakes along the creek, and occasionally a coyote or a deer can be seen crossing the sandbars downstream. Once or twice I have surprised egrets or graceful herons at the water's edge. Later in the day, when the lowering sun stretches the mosaic of shadows on the ground into a long and linear pattern, hawks often cruise for field mice in the grassy sloping floodplain across the creek. But timeless as it seems, this sandy bluff is in fact an archive documenting a

somewhat changeable environment. The record, or at least the part of it that we know, extends backward to the end of the Wisconsinan glacial stage.

The deposits at the base of Berger Bluff give considerable geologic evidence for changes in the character of Coleto Creek as well as the area it drains. Berger Bluff itself did not yet exist in the late Wisconsinan, although there were bluffs, or at least a valley slope of about the same height, cut into the Goliad Formation and Lissie and Beaumont terrace deposits in the immediate vicinity. Probably the valley margins varied from sloping to steep-sided at times, depending on the availability of protective plant cover and whether the creek happened to meander against the valley margin to form a cutbank. Coleto Creek was apparently deeper, narrower, considerably muddier and more sinuous, flowing over a floodplain that was lower and flatter, but not much wider in most places than at present. Extreme floods appear to have been less common (at least until about 8500 BP), with the annual flow of the stream more evenly distributed. Floodplain vegetation was probably adapted to wetter conditions, with less severe or frequent flood damage. Throughout the Holocene, Coleto Creek continued to deposit alluvium on its floodplain with little or no evidence of erosion. This continual aggradation seems to have taken place despite the fact that the ultimate base level for the creek — the Gulf of Mexico — had ceased to rise by about 4000 BP. At some point (perhaps near the end of the Late Prehistoric; the dating is uncertain and will be discussed at length in a later chapter) aggradation ceased and Coleto Creek experienced a major change in hydraulic regime, and began cutting down to its present grade. The creek has now cut down through all of its Holocene deposits and is incising sediments that were deposited at the Pleistocene/Holocene boundary.

The site lies 82 km from today's Gulf coast, measured from the seaward side of the Holocene barrier island (Matagorda Island), and 30 km from Green Lake, the drowned head of the Pleistocene Guadalupe River valley. During the Late Pleistocene, however (at, for example, eleven to twelve thousand years before present), with sea level in the Gulf about 40 to 60 meters lower than at present, the Gulf coast would have been positioned about 50-70 km farther to the southeast, leaving Berger Bluff a thoroughly inland 150-170 km from the coast (Berryhill 1981a, 1981b, Beeville and Corpus Christi quadrangles). This is about the same distance from the coast as Hallettsville or Karnes City, under modern conditions. This Late Pleistocene positioning of the Gulf would have tended to make the Coleto Creek basin climate slightly more continental in nature, just as present-day Hallettsville or Karnes City are less affected by Gulf temperatures or moisture than is Victoria.

HISTORY OF DISCOVERY AND INVESTIGATION

Berger Bluff has been well known locally for many years. A human burial (with worn teeth) washed out of the cutbank years ago and was collected by Nelson Pantel and others. Although the burial was reportedly found in cohesive sediments (Nelson Pantel, personal communication), its stratigraphic position is unknown, and it seems unlikely it relates to the earliest occupations of the site. The remains have since been lost. Local avocational archeologists Bill Birmingham, Smitty Schmiedlin, Sonny Timme, and Ed Vogt have all observed the site for years and have made collections from it. Timme, for example, monitored the site regularly from 1956 to 1960; Birmingham monitored the site in the early 1960's and has contributed from recollection some useful observations on the appearance of the site before flooding spawned by Hurricane Beulah in 1963.

The planned construction by the Guadalupe-Blanco River Authority (GBRA) and Central Power and Light Company of a coal-fired power plant and a large cooling reservoir on Coleto Creek south of the site provided a stimulus for formal studies of the site, for the 98 foot normal pool level is very near the top of the bluff. In 1975 the GBRA contracted with the Center for Archaeological Research at the University of Texas at San Antonio to begin a program of survey and testing in the reservoir area, and the Berger Bluff site was first recorded by a UTSA survey crew the same year (Fox and Hester 1976). The site is a Texas State Archeological Landmark and has been determined eligible for nomination to the National Register of Historic Places (but is not listed). Test excavations were dug in the spring of 1977. Two test pits were excavated to depths of 1.90 and 1.65 m below the blufftop surface, the latter in a portion of the site designated 41 GD 30B, farther upslope and well back from the edge of the cutbank (Fox, Black, and James 1979). The part of the site which is of primary concern here has been designated 41 GD 30A, and in June, 1979, a UTSA crew returned to this part of the site and excavated a 3 x 4 m block on the blufftop, a few meters back from the edge, to a maximum depth of 2.54 m below ground surface (maximum depth was achieved only in two one-meter squares). These excavations are reported by David Brown (1983). During this phase Victoria avocational archeologist Sonny Timme discovered some small bits of charcoal embedded in the sloping surface of an erosional bench about seven and a half meters below the blufftop surface. A 1 x 1 m excavation unit, designated "Unit 2," was laid out and excavated to a maximum depth of 32 cm below the bench surface, revealing a small hearth *in situ*. Charcoal collected by Timme from the hearth gave a radiocarbon date of 11,550±800 BP (Tx-3569). The date helped to confirm the considerable antiquity of the lower deposits, and to dispel doubts that the materials observed in the lower deposits were *in situ*. At the same time, consulting geologist Glen

Evans, who many years ago had done the geologic study of the Berclair terrace associated with the Buckner Ranch sites (Sellards 1940), inspected and recorded the stratigraphic section exposed in the cutbank. The combined weight of Evans' assessment of the lower, or bench deposits, and the radiocarbon date from the hearth left little doubt of the significance of the bench area. Accordingly, more excavations on the bench were sponsored by the GBRA for three weeks with a crew of four during November and December, 1979, in compliance with the National Historic Preservation Act of 1966 (as amended) and its implementing regulations, 36CFR800; the National Environmental Policy Act of 1969; and Executive Order 11593. This work was done under Texas Antiquities Committee Permit No. 80, with Thomas R. Hester as principal investigator. I supervised the field work and was assisted by Will Goetzmann, Dan Potter, Lang Scruggs, and Don White, along with volunteers listed in the Acknowledgments. Later, I continued to work at the site sporadically, on an unfunded basis with volunteer help (mostly from Victoria avocational archeologists) from January to April, 1980. Work on the lower deposits ended on April 18, 1980, with the rising water of the reservoir about 30 cm below the edge of the lowest excavation unit. It should be noted that although less excavation was accomplished, the volunteer phase of the project produced some of the most important data to come from the site. None of this would have been possible without the contributions of interested local residents and CAR archeologists who worked in weather ranging from warm, to cold and rainy, to sniveling cold.

In the summer of 1983 further work was done at Area B and at another site downstream (41 GD 31) to assess the impact of the planned construction of Flume #3 for the cooling reservoir. Several backhoe trenches were dug in and around area B by a

UTSA crew. This work, which is reported elsewhere (Brown 1986) contributed some useful geologic information.

CONTEMPORARY CLIMATE

The Berger Bluff catchment (Fig. 1.12) is located in the subtropical humid climatic zone of east Texas, although the boundary with the subtropical subhumid zone lies only a short distance to the southwest (Larkin and Bomar 1983:2). It is part of the South Central climatic division of the National Weather Service. Average annual rainfall declines rather rapidly westward from this area. The nearest first-order weather station is at the Victoria Regional Airport, located 25.75 km (16.0 miles) to the east-northeast of Berger Bluff. Yorktown is the only weather station actually located within the catchment, and it measures only precipitation. Victoria, Cuero, and Goliad are the only temperature recording stations (the Cuero and Goliad stations also have a history of location shifts). Although the smaller weather stations are operated by volunteer observers and frequently have incomplete data (days when nothing was recorded), they are located closer to the catchment and may give a better picture of local rainfall averages. Table 1.3 shows precipitation and temperature recorded at Yoakum (DeWitt County), Goliad (Goliad County), Victoria (Victoria County), plus precipitation measured at Yorktown and Cuero (DeWitt County), and Runge (Karnes County).

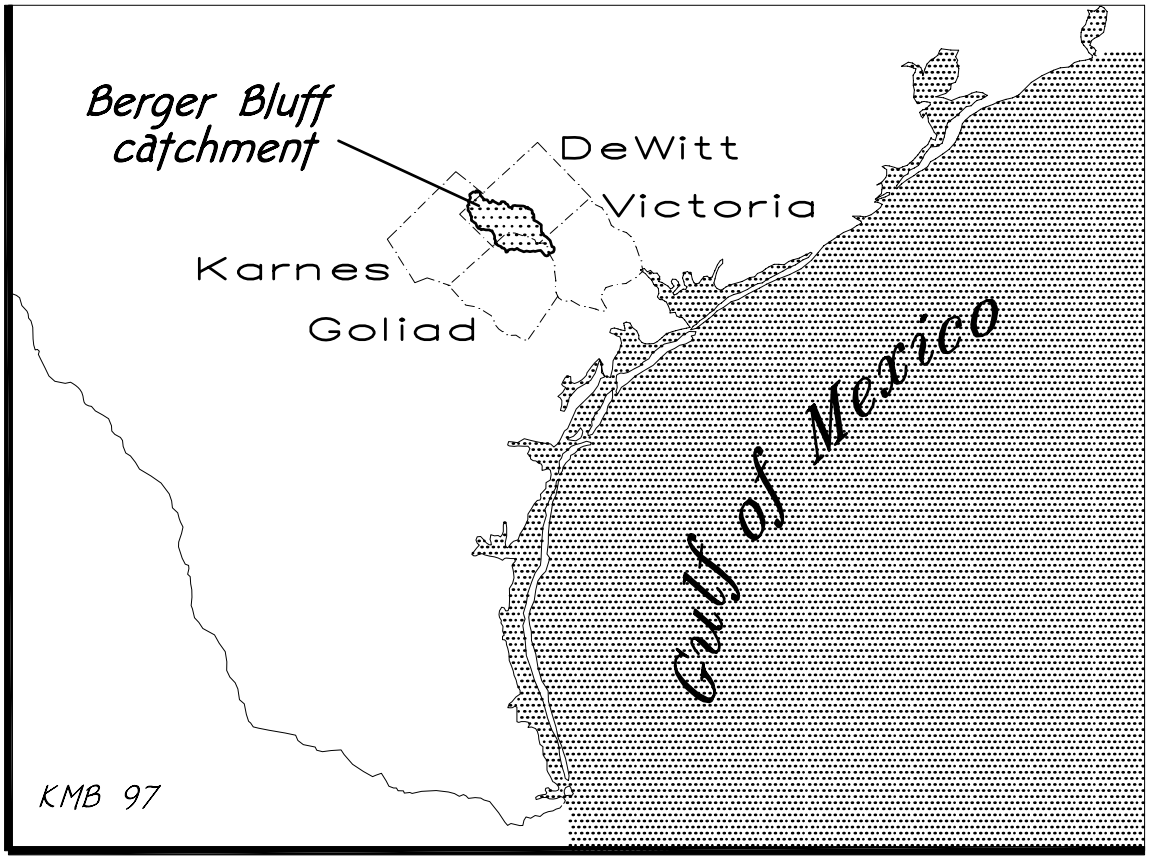


Figure 1.12. Location of the Study Area. The four-county area enclosing the Berger Bluff catchment is shown. Figure 1.26 shows a slightly more detailed view of the region.

Table 1.3. Contemporary Climate Data for the Berger Bluff Environs.[1]

Station: *County:*	**Yoakum** **De Witt**	**Goliad** **Goliad**	**Victoria** **Victoria**	**Yorktown** **De Witt**	**Cuero** **De Witt**	**Runge** **Karnes**
Earliest records available	1917	1912	1946	1947	1901	1897
Period of record	1951-1980	1951-1980	1951-1980	1948-1980	1948-1980	1948-1980
Mean temperature	70° F 21.11° C	71° F 21.67° C	70° F 21.11° C		69° F 20.55° C	
Daily minimum	59° F	82° F	80° F			
Growing season	270 days	285 days	290 days			
Mean precipitation	36.2 in 92.0 cm	36.8 in 93.5 cm	35.0 in 93.7 cm	32.6 in 82.8 cm	36.2 in 91.9 cm	30.4 in 77.2 cm
Record precipitation	55.24 in 140.03 cm	55.35 in 140.07 cm	59.57 in 151.40 cm			
Potential evapotranspiration			62.24 in 158.10 cm			
Soil moisture deficit			39.66 in 100.07 cm			
Days/year with thunderstorms	49	49	49			

[1] Data from National Fibers Information Center (1987, data 1951-1980), Eagleman (1976, data 1931-1960), and NOAA (Climatological Data for Texas, data 1948-1980). *Missing data:* Yorktown precipitation data, 1953-54; Runge precipitation data, 1949; Cuero temperature data, 1950-51, 1952-53, 1963, 1969-70, 1972-77; precipitation data missing for 1974.

The Berger Bluff catchment and the area around it generally gets about 84-94 cm (33-37 inches) of rainfall annually, with a standard deviation of about 20-27 cm at any one station, and an average of about 49 days per year with thunderstorms. Snowfall is so infrequent that it can essentially be disregarded in the precipitation statistics. The record snowfall of February 12-15, 1895 (twelve inches at Victoria; Griffiths and Ainsworth 1981:26) was a very rare event. Like the rest of Texas, the region experienced record low rainfall in the mid-1950s drought. Yorktown received only 38.1 cm (15 inches) and the Goliad 1 SE station received only 35.2 cm (13.85 inches) of precipitation in 1956. That is nearly as dry as the long-term average for Sanderson. The highest annual rainfall for Yorktown during the period of record was 143.4 cm (56.56 inches) in 1973, which is comparable to the long-term average for Port Arthur. When data for the entire period of record (1948-1996) are used, the mean annual precipitation at Yorktown rises to about 88 cm (Table 1.4), higher than that shown in Table 1.3 because Table 1.4 includes several rainy years in the 1980s and 1990s.

Average annual temperature is slightly over 21º C (70-71° F); the standard deviation is about 2° C at Cuero and Goliad. Daily highs run about 27-28º C, daily lows slightly over 15º C. The growing season is about 270-290 days per year (74-79% of the year). Because of its nearness to the Gulf, the region has a fairly maritime climate at present, ranging at Victoria from an average minimum temperature in January of about 6º C (43º F) to an average maximum in July of about 34º C (93.5ºF). As Fig. 1.13 shows, the maritime climate of the Berger Bluff catchment translates to a low continentality index, although the area is slightly more continental than adjacent parts of the coastal plain.

Table 1.4. Contemporary Precipitation at Yorktown.

Year	ENSO year	Precipitation (cm)	Precipitation (inches)	Year	ENSO year	Precipitation (cm)	Precipitation (inches)
1948	C	57.71	22.72	1973	C	143.66	56.56
1949	C	103.48	40.74	1974	N	87.76	34.55
1950	N	M		1975	C	71.60	28.19
1951	W	66.50	26.18	1976	W	131.09	51.61
1952	N	95.40	37.56	1977	N	89.33	35.17
1953	N	M		1978	N	77.19	30.39
1954	C	M		1979	N	113.92	44.85
1955	C	57.28	22.55	1980	N	72.77	28.65
1956	C	38.10	15.00	1981	N	127.15	50.06
1957	W	110.21	43.39	1982	W	99.29	39.09
1958	N	107.21	42.21	1983	N	88.34	34.78
1959	N	86.26	33.96	1984	N	71.70	28.23
1960	N	114.05	44.90	1985	N	M	
1961	N	66.93	26.35	1986	W	M	
1962	N	75.69	29.80	1987	W	M	
1963	W	49.94	19.66	1988	C	M	
1964	C	63.75	25.10	1989	N	65.48	25.78
1965	W	92.89	36.57	1990	N	76.53	30.13
1966	N	66.65	26.24	1991	W	115.44	45.45
1967	C	128.52	50.60	1992	N	101.45	39.94
1968	N	96.16	37.86	1993	N	81.66	32.15*
1969	W	111.91	44.06	1994	N	94.97	37.39
1970	C	73.46	28.92	1995	N	57.15	22.50
1971	C	97.00	38.19	1996	N	50.19	19.76
1972	W	97.00	38.19				
					Mean:	87.45	34.43
					SD	24.21	9.53

N = 42 of 49 years
M = missing or incomplete data
* incomplete data

ENSO Years

	C = cold years	**N = neutral years**	**W = warm years**
Mean (cm)	83.46	85.39	97.14
Standard deviation (cm)	32.05	18.86	23.73
Coefficient of variation	.384	.221	.244
Number of years	10	23	9

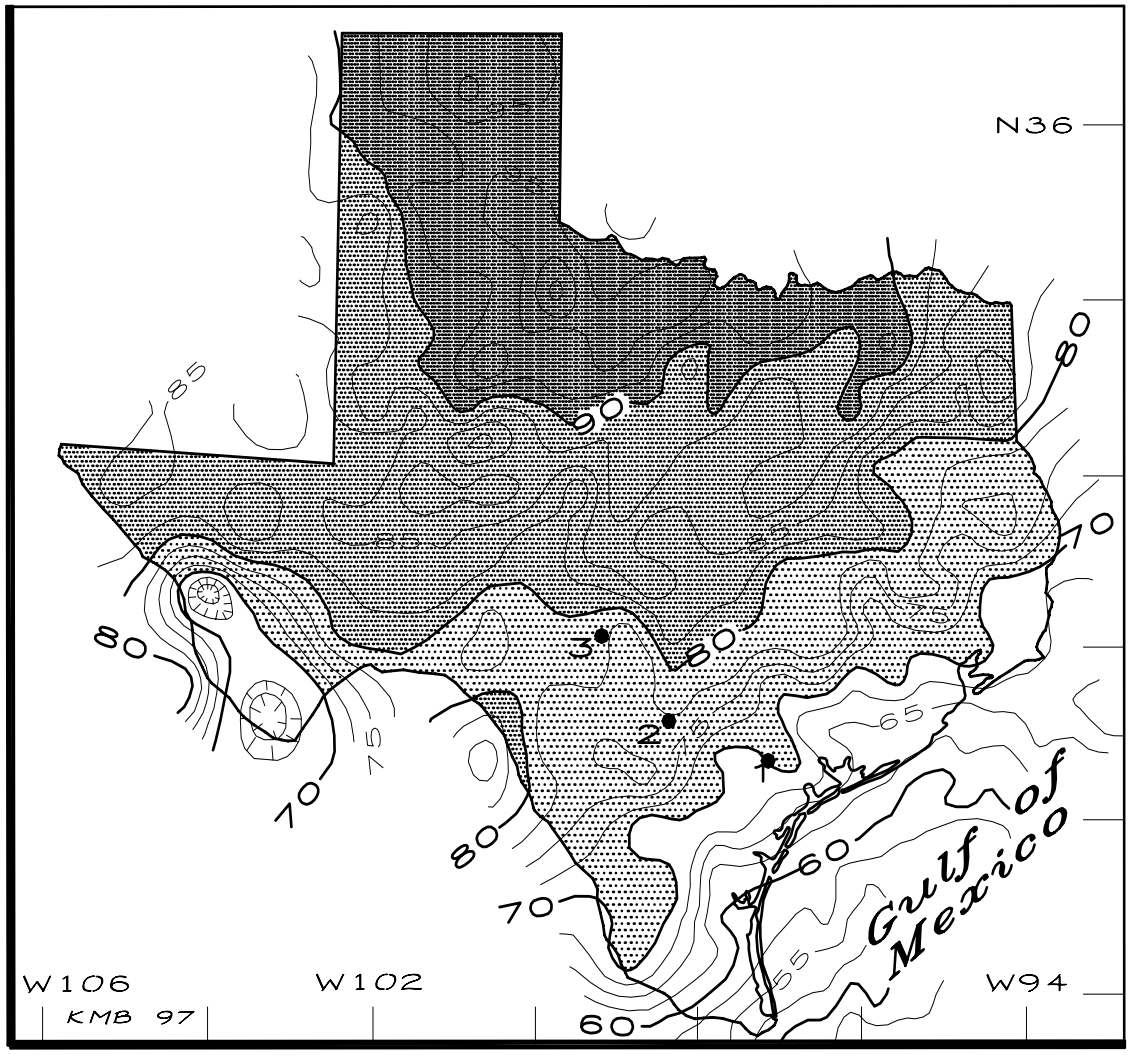


Figure 1.13. Isopleth Map of Continentality Index for Texas. Distribution of continentality (seasonal severity of climate), based on Conrad's (1946) continentality formula. Continentality is reduced along the Gulf coast and in the Chisos Mountains, highest in north Texas and the Panhandle. Berger Bluff is located in a part of the state that is less climatically sensitive. Note that absolute values differ from Figure 1.1, which uses a slightly different formula. Data for Texas (1951-80) are from Natural Fibers Information Center (1987); for surrounding US states (1951-73, 1951-74) from Ruffner (1980); for Mexico (mostly 1961-70), Mosiño Alemán and García (1974) and NOAA (1979). Numbered localities: 1 = Berger Bluff, 2 = Richard Beene site, 3 = Hall's Cave.

Although the boundary of the subhumid climatic region lies to the southwest, it would only require a slight reduction in annual rainfall or a small increase in evaporation rate to move the boundary across the catchment to the northeast. There are some indications that this may have occurred in the past. A scatter of large playa lakes can be seen on the Lissie Formation north of Refugio (about 24-43 km from Berger Bluff); particularly good examples can be seen on the USGS Live Oak Lake and Ryanville quads. Although flooded now, these interesting features appear to have well-developed lee dunes on the south side, suggesting at least seasonal desiccation and strong winter winds from the north (departing from the prevailing southeasterly winds; see *wind* discussion below). These playas are unstudied and undated, but suggest very strong, dry, meridional air mass movement, presumably sometime during the Holocene (?). Aronow (1982:88-89) discusses similar depressions on the Willis Formation. Other dunes on the Beaumont Formation near Tivoli date about 1100-1200 cal BP (Otvos 2004:Table 4). Despite this documented potential for aridification, most of the vertebrates and invertebrates recovered from archeological deposits at Berger Bluff (both in the bench deposits and in the late prehistoric midden at the top of the bluff) have affinities to the more mesic east (east Texas and eastern US). The present-day geography of climatic regimes as portrayed by Larkin and Bomar probably had no parallel in the Pleistocene, when the geographic organization of regional climate may have been radically different.

Rainfall in the catchment

Like the rest of south Texas, maximum rainfall in the Berger Bluff catchment occurs in the months of May and September, under the present-day climatic regime (in neutral ENSO years), separated by summer and winter dry seasons. In years with warm ENSO events, extra winter rainfall may occur. Most grasses in the catchment are adapted

to warm-season growth that depends on the pulse of moisture received in late spring. At Yorktown, the only weather station within the catchment, average May rainfall from 1959 to 1979 was 11.66 cm; September rainfall was 14.45 cm; and the driest month was March, with 3.12 cm. In Figs. 1.14 and 1.15 the average monthly rainfall for the same period has been contoured on Yorktown and the four stations closest to the catchment (Runge, Goliad, Cuero, and Victoria). In general, the isohyets in most months parallel the geologic outcrops, indicating a potential for seasonal bias in sediment contribution by different formations. The principal contrast is between the summer months of June, July and August, and the rest of the year.

Five patterns of spatial distribution of rainfall seem to occur:

1. winter (November through February; and April): light rainfall (except in *El Niño* years), decreasing with a south-southeasterly trend;

2. spring (March, May): heavy rainfall in May produced by south-southeasterly diminishing frontal systems;

3. summer (June, July): rainfall decreasing northwest-ward, away from the coast; convective thunderstorms;

4. late summer (August): rainfall decreasing northward; convective thunderstorms with unusually high rainfall at Yorktown;

5. early fall (September, October): rainfall decreasing northwestward, with heavy rainfall in some years produced by tropical hurricanes from the Gulf.

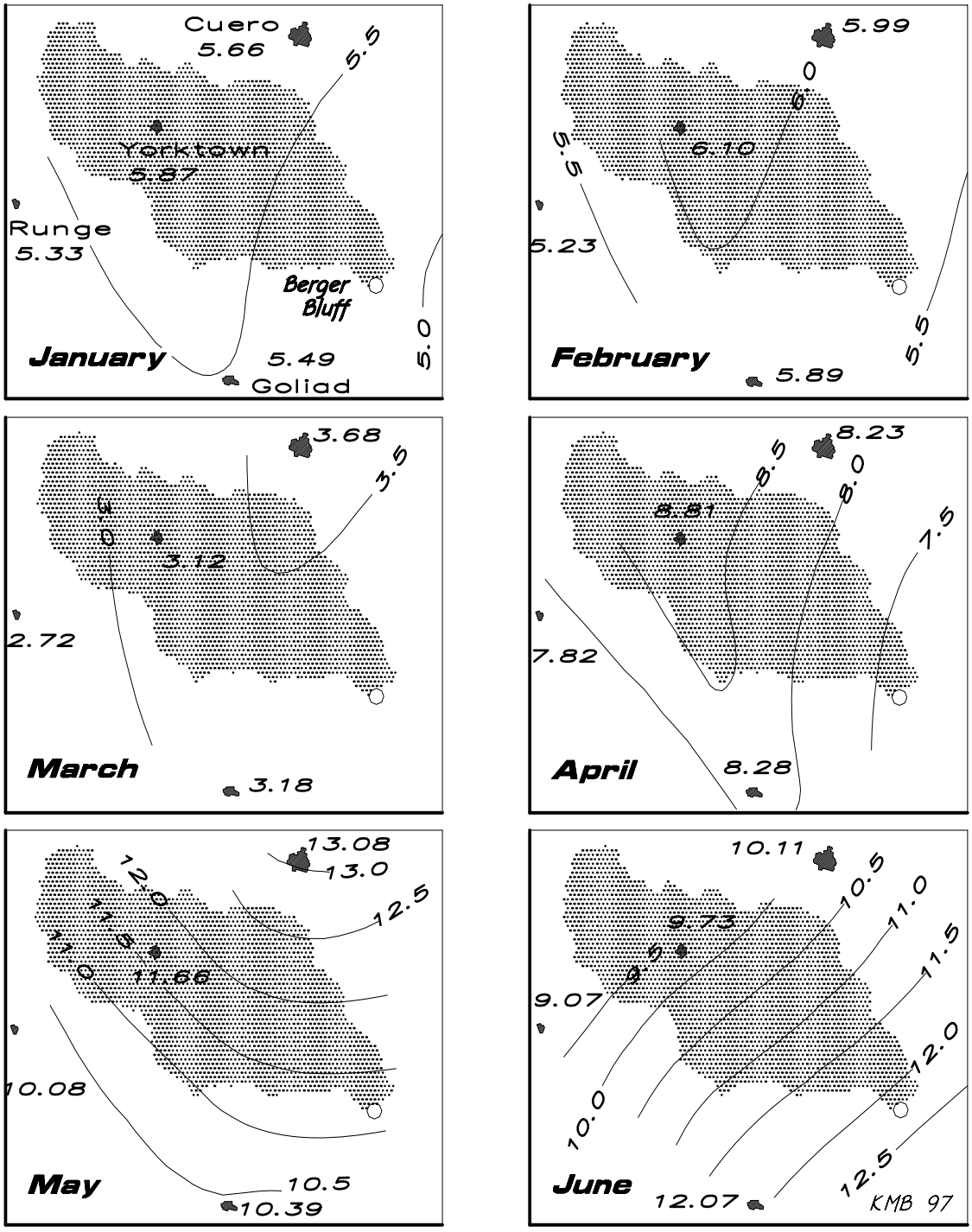


Figure 1.14. Precipitation in the Catchment, January-June. Averaged NOAA data (1959-79) from Victoria plus the four stations shown in the first panel; contoured at half-centimeter intervals. The average for each month (in cm) is shown beside each station.

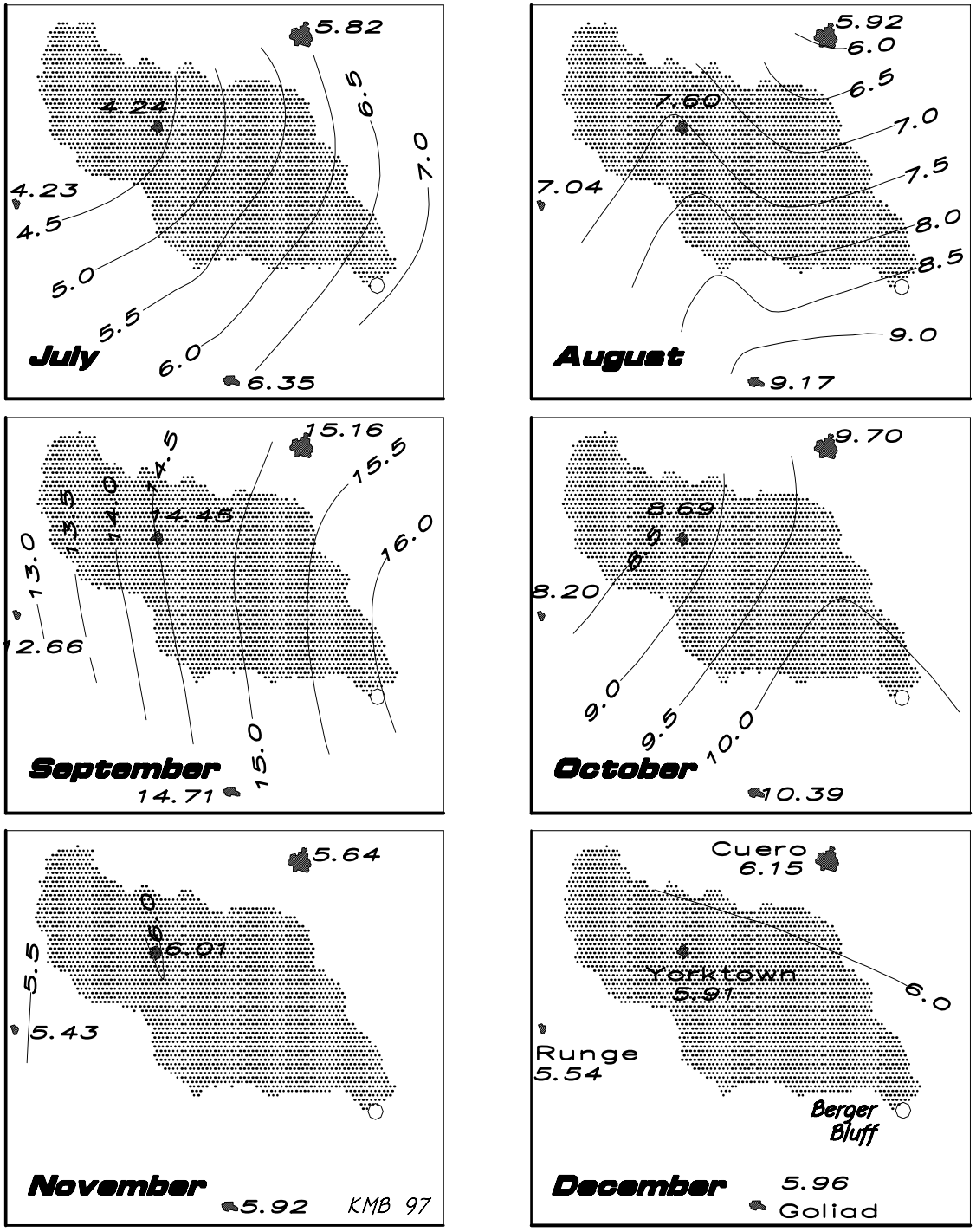


Figure 1.15. Precipitation in the Catchment, July-December. Averaged NOAA data (1959-79) from Victoria plus the four stations shown in the last panel; contoured at half-centimeter intervals. The average for each month (in cm) is shown beside each station.

Cuero has a bimodal April-September precipitation pattern [1942-76 data; Gustavson, Reeder, and Badger (1980:Fig. 5)]. Annual precipitation data for Beeville and Victoria show the same bimodal May-September pattern, but Beeville also has a third rainfall peak in early November, while Victoria shows a prominent peak in mid-June (1961-1996 data downloaded from NOAA via the World Wide Web). This suggests there are tertiary rainfall peaks that differ from station to station, and probably vary over different periods of record, as well. Further investigation might show the November peak at Beeville originates in ENSO warm event years.

Wind

The only weather station near the catchment to record wind direction is the Victoria airport. Fig. 1.16 is a wind rose showing directional frequencies for wind at the Victoria station from 1968 to 1978. It shows that the most common origin for wind is to the southeast (azimuth N130° E to N160° E), chiefly from March through August when insolation rates and diurnal heating are high. Wind from this direction originates as a daytime land-sea breeze. During the day, the land heats faster than the adjacent Gulf, resulting in lower air pressure over the land and consequent air flow (the "sea breeze") from water to land; at night, the process reverses. Even though the airport is about 85 km from the open Gulf, the sea breeze dominates wind direction. A secondary origin for wind is northerly (azimuth N0º E to N30º E), chiefly from November through February, due to winter intrusion of frontal airmasses from the northern Plains. This kind of wind is likely to originate both during the day and at night. Another secondary wind source is easterly to east-northeast (azimuth N50º E to N90º E), occurring chiefly from September through November.

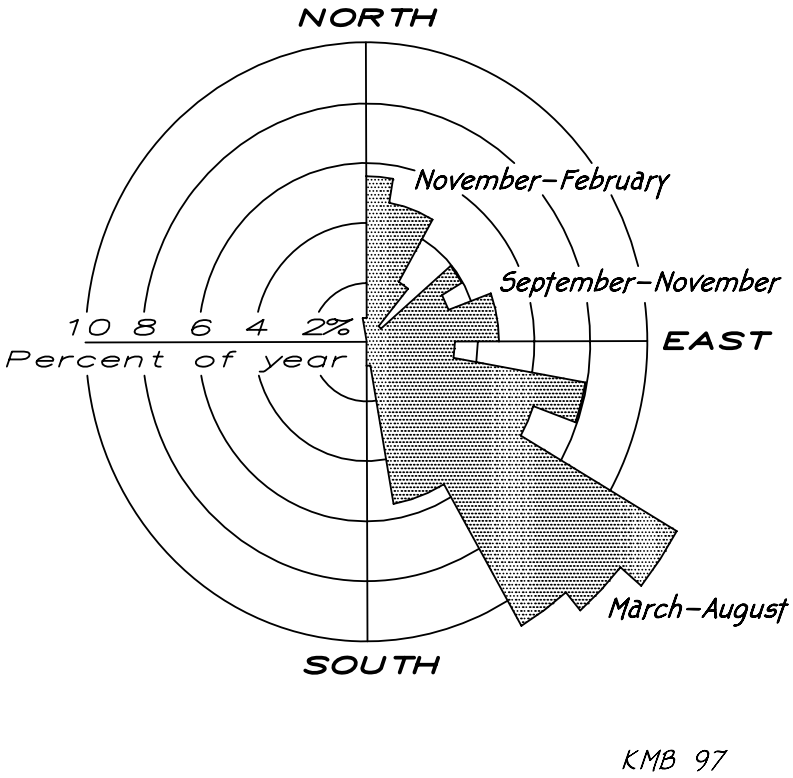


Figure 1.16. Average Annual Wind Direction, Victoria Airport. Wind rose shows prevailing direction in ten-degree increments as a percent of the annual total. The three major peaks are identified by month (source: NOAA Climatological Data for Texas, 1968-1978).

Larkin and Bomar (1983:138-141) also show wind roses from the Victoria airport, based on 1961-1980 data and segregated by season. Their diagrams also include wind strength, however, and look somewhat different from the one I have shown here.

Wind direction will become significant when I discuss the evidence against eolian origin of sediments at Berger Bluff, in a later chapter. For now, the reader should note that northerly winds are much less common and prolonged than southeasterly winds, although they may be strong (18 knots and above; Larkin and Bomar 1983:138).

CONTEMPORARY FLORAL ASSOCIATIONS

Vegetation in the catchment can be variously characterized depending on the scale of mapping. Statewide vegetation maps simply show the area around the site as post oak woodland or "oak-hickory forest" and the upper basin as "mesquite-chaparral savanna." Vegetation mapping by the Bureau of Economic Geology (Fig. 1.17) shows that the vegetation is to a large extent edaphically controlled (Smeins and Diamond 1983), with association boundaries following geologic formations closely. The Bureau map shows a belt of "oak/ huisache/ elm woodland" (C5) surrounding the site, with a belt of "oak-acacia woodland" (C6) to the west. These essentially occupy the Goliad Formation, the latter belt sitting atop the higher and better-drained part of the cuesta. To the east is the Lissie Formation, occupied by a savanna association ("bluestem/ indiangrass/ oak," B3). The contact between the Goliad and Lissie formations corresponds rather closely to the contact between these woodland and savanna associations. The upper part of the Berger Bluff catchment is covered by "mesquite-condalia chaparral" [A4, essentially the brushy southwestern extension of the Fayette Prairie (Smeins and Diamond 1983)], with the head of the catchment lying in another belt of oak-acacia woodland (C6). These lie on the Fleming, Oakville, and Catahoula formations. Most of the "A4" area of the catchment looks as if it might have been former prairie, first converted to cropland and now to pasture, with grass or in some cases, broomweed and other weedy invaders, along with scattered huisache trees (Fig. 1.18). Streamcourses are generally intermittent, often with gallery thickets of huisache.

Figure 1.17 *(following page, landscape orientation).* Contemporary Floral Associations In and Near the Berger Bluff Catchment. Adapted (with permission from the Bureau of Economic Geology) from the *Biologic Assemblages* map in the Guadalupe-Lavaca-San Antonio-Nueces River Basins Regional Study map series (*Austin West-Seguin West* sheet, 1985; *Beeville West* sheet, unpublished). Floral units are as follows:

Prairie/Savanna

B2: Bluestem-oak-elm-honey locust, moderately dense blackland prairie

B3: Bluestem-Indiangrass-oak, moderately dense to dense, prairie grassland with oak motts and brush

D1: Mesquite-acacia-condalia, moderately open to locally dense savanna

D3: Mesquite-oak, moderately open to dense savanna

Chaparral

A3: Blackbrush-guajillo-ceniza, moderately dense

A4: Mesquite-condalia, moderately dense to dense

Open woodland

C5: Oak-huisache-elm, open to moderately open

Woodland

C6: Oak-acacia, moderate to locally dense

E1: Oak-elm-pecan-cottonwood, moderately dense to dense riparian woodland

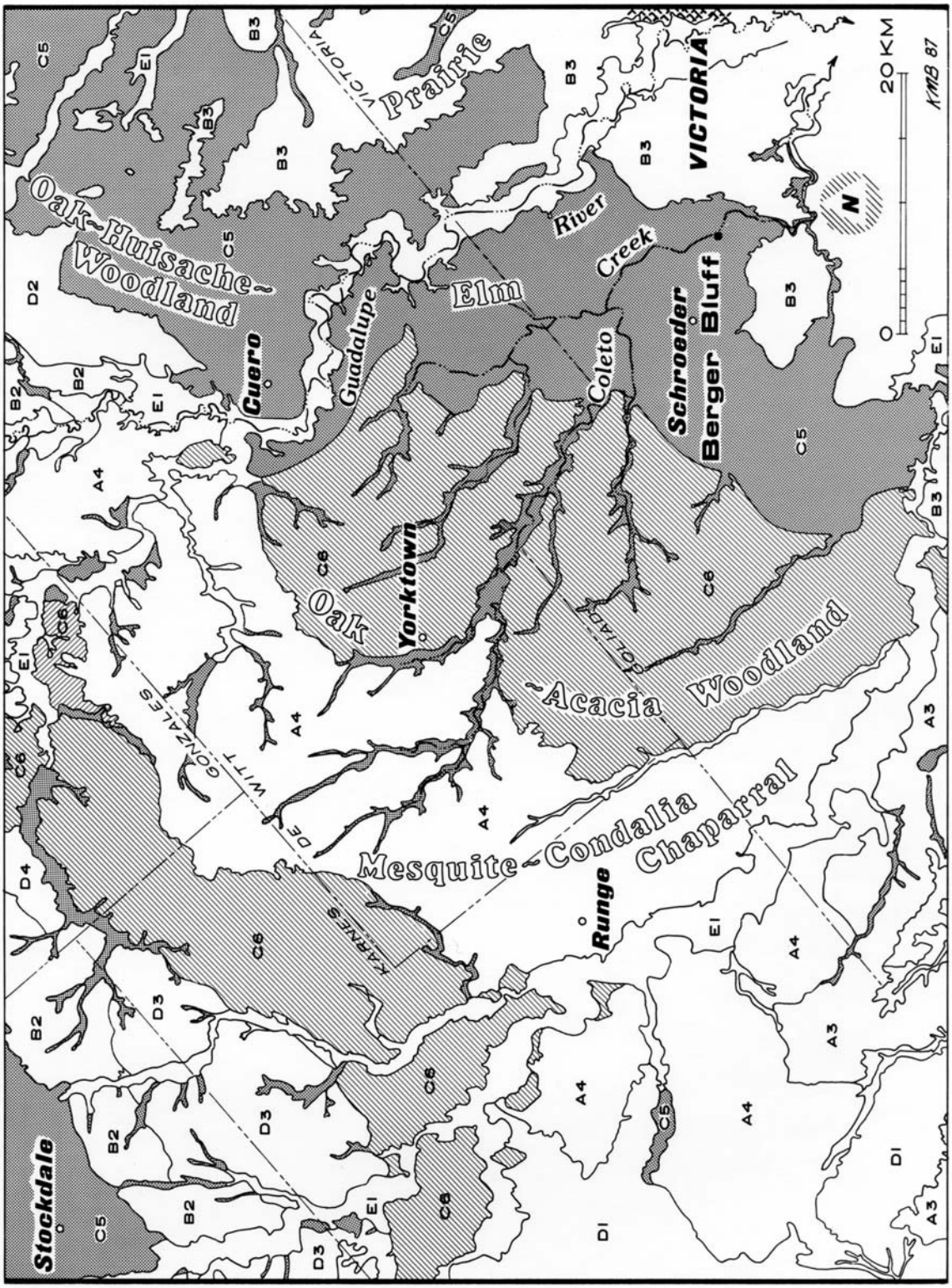

Prairie
Oak-Huisache-Woodland
Elm
Creek
River
Guadalupe
Cuero
Yorktown
Oak
Coleto
Schroeder
Berger Bluff
VICTORIA
Acacia Woodland
Mesquite-Condalia Chaparral
Runge
Stockdale
GONZALES
WITT
KARNES
DE LEON
VICTORIA
N
0
20 KM
KMB 87

Figure 1.18. Prairie on the Oakville Escarpment. Looking east at southeastward-sloping terrain near crest of cuesta, just inside the DeWitt/Karnes County line west of Old Davy. Improved pasture with scattered mesquite trees; Sarnosa fine sandy loam on Oakville Formation, Salt Creek drainage.

Most of the catchment, then, is covered by three major plant associations (C5, C6, and A4), arranged roughly into thirds, becoming progressively more open and arid-adapted as the more elevated and better-drained head of the catchment is approached to the northwest. Except for the belt of post oak woodland at the head of the catchment in Karnes County, the proportion of tree canopy diminishes up-basin, while the proportion of chaparral and grasses increases. The heaviest belts of woodland are near Berger Bluff and downstream from it, but even here the densest woodland is confined to terrace remnants adjacent to Coleto Creek and its tributaries; interfluvial areas are much more open (Fig. 1.19). These are gallery forests, but they occupy elevated terraces rather than the present floodplain.

Figure 1.19. Upland Prairie. Pasture with scattered large live oaks on Goliad Formation, about two miles east of Upper Meyersville, DeWitt County.

There is a surprising number of pine trees in and around the catchment, especially on the sandy Fleming Formation. All of them appear to be introduced. I assume these are all loblolly pine (*Pinus taeda*). Many farmhouses in the region have one or two pine trees planted in the yard. There is even a small pine grove on the east side of Yorktown, near the American Legion hall (Fig. 1.20). Although these pines are not native to the catchment now, and presumably cannot compete with native vegetation except when the natives are removed and replaced with planted trees, they all appear to be thriving, and many appear to be at least a couple of decades old. Since these pines appear to thrive under current climatic conditions, I would guess that the substrate is suitable, and the contemporary climate is only slightly beyond the tolerance of the species. The Lost Pines

variety of loblolly pine is better adapted to drought than east Texas varieties (Hacker and Bilan 1995). This suggests pine could have been a minor but significant component of catchment vegetation during the Pleistocene. The nearest stand of apparently native, non-introduced pines that I am aware of is located on Sandies Creek, just south of Leesville, about 32.5 km (20.2 miles) NNW of the head of the catchment.

Figure 1.20. Pine Trees at Yorktown. Stand of introduced loblolly pines on the eastern outskirts of Yorktown, DeWitt County.

Pinus taeda is a southeastern species. In its present distributional core, the optimum January temperature is about 7º C (range, 0.1-15.8º C), July 28º C (range, 21.4-29.0º). Optimum precipitation is over 10 cm/month in both January and July (range, 5.6-15.0 cm in January and 4.7-21.4 cm in July; Thompson, Anderson, and Bartlein 1999b).

The catchment was settled by German immigrants in the 1840s, after which bison and antelope were replaced first by free-ranging cattle, then fenced cattle. Dobskyville

was settled in 1847. Coletoville and Meyersville were both reportedly founded in 1849 [although another source (Jacob and Egg 1978:3) says the Meyersville area was first settled in June, 1846 and the historical marker in town says 1843]. An 1864 Confederate map of the region (part of which is reproduced in Fox and Livingston 1979:Fig. 2) indicates the post oak belt schematically and shows the extent of woodland in the Coletoville-Berger Bluff area when the basin was still thinly settled. Domenech (1858:146-147) in an undated passage probably referring to the period about 1849, described the Goliad to Victoria trail as follows:

> The country is very fertile; and maize is every where cultivated, while magnificent tracts of rich pasturage support large herds of fine oxen, horses, and sheep. We next crossed the Coleto, which runs through an extensive prairie, and like all the rivers of Texas is bordered on each side by trees of great height and strength, which grow so closely to each other, and are, besides, so interlaced with the wild vine, ferns, and underwood, that in some places it is impossible for either man or beast to force a passage through them.

Old church records from St. John Lutheran Church at Meyersville recount that

> More settlers came and settled on the right and the left banks of the Twelve-Mile Coleto, especially in the years from 1855-1859. The raising of cattle became especially profitable because of the grass which in the beginning of the settlement was so tall that it was almost impossible to walk in (Jacob and Egg 1978:4).

Native grassland has been severely reduced by 160 years of fire suppression, which has allowed chaparral to increase, and heavy grazing pressure, which has thinned ground cover, removed tall or mid-grasses (little bluestem, switchgrass, and indiangrass), and allowed their replacement by "increaser" and "invader" species (see Gustavson, Reeder, and Badger 1980:91). Some areas have been converted from rangeland to improved pasture. Mechanized chaining of brushland first became widespread in south Texas in the 1950s.

More detailed mapping can be found in environmental impact statements for two areas in the catchment. A study by Gustavson, Reeder, and Badger (1980:91-92; Table D1) includes a small part of the northern side of the catchment in the Threemile Creek and Fivemile Creek drainages. Their map (Gustavson, Reeder, and Badger 1980:Fig. 25) shows mostly grassland and parkland, with woodland along Fivemile Creek. A quantitative and much more detailed study of the vegetation in the Coleto Creek reservoir and power plant project area can be found in Espey, Huston & Associates (1976). The final impact statement for the power plant (Environmental Protection Agency n.d.) is simply a summary of that work, and contributes no new information.

The Espey, Huston & Associates pre-construction baseline study (1976) sampled five different kinds of "stands" in the Coleto Creek power plant project area; the entire project area is within the Bureau of Geology's "C5" association, but at this level of detail, it can be seen that there are different kinds of woodland, brushland, and grassland embedded within the post oak belt. The following descriptions are abstracted from the text and tables in that report:

1) *Live oak stand*. Live oak (*Quercus viginiana*, 580 trees per hectare) with sugarberry (*Celtis laevigata*), coma (*Bumelia lanuginosa*, or gum bumelia), yaupon (*Ilex vomitoria*) and persimmon (*Diospyros texana*) in the understory. Leaf litter comprises over 70% of the ground cover, along with grasses (Paspalum, basketgrass and bristlegrass). Frostweed occurs under the canopy.

2) *Post oak stand*. The overstory is about 67% post oak (*Quercus stellata*, 627 trees per hectare), 22% blackjack oak (*Quercus marilandica*, 160 trees per hectare), and

11% live oak (80 trees per hectare). On the Lissie terrace surface in the immediate south and southwest of Berger Bluff, most of the post oak occurs in a parkland setting, with individual trees rather widely spaced, and almost no understory (reportedly due to grazing pressure). This area looks very much like a photo shown by Schmidly (1983:15). The oldest and largest of these post oaks are about 300 years old, as shown by tree-ring studies (to be discussed later). Other species include chittamwood, yaupon, hackberry, mesquite, yucca, and prickly pear. Species of *Panicum*, *Paspalum*, smutgrass, three-awn, lovegrass, and knotroot bristlegrass are the chief ground cover. Table 1.5 shows the nature of the heavily grazed ground cover in the Coleto Creek power plant project area, based on fall and spring samples; most of the cover is perennial grasses and annual forbs. Little bluestem now represents less than one percent of the ground cover. Most of the grasses are native warm-season grasses, but smutgrass is introduced, and Scribner's panicum, round-seed panicum, little bluestem, and ozarkgrass are cool season grasses, probably depending on both the May and September pulses of moisture for sustained growth. Both C3 and C4 photosynthetic pathways are represented. Cool season grasses begin growing in early spring and continue well into the fall season; growth of warm season grasses is confined to the summer warm season. Leaf litter represents 57-66% of ground cover, while about 18-19% is bare ground.

Schmidly (1983:16) notes that

> In the past it is probable that the grass layer in the entire post oak region was dominated by bluestems and their tall-grass associates wherever light could reach the ground. However, under heavy human use, which has severely affected the whole region, most openings maintain a vegetation of low grasses such as threeawns, panicums, lovegrass, and others.

Table 1.5. Ground Cover in Post Oak Stand, Coleto Creek Power Plant Project (source: Espey, Huston and Associates 1976:Tables 2-9, 2-10; ground cover only, sorted by % cover, zero coverage taxa omitted).

Taxon	Common name	Percent cover	Code*	Path	$\delta^{13}C$
October, 1975 sample					
Sporobolus indicus	smutgrass	3.1	WPI	C4	
Aristida longespica	Kearney three-awn	2.6	WAN		
Eragrostis oxylepis	lovegrass	2.2	WPN [1]	C4	
Setaria geniculata	knotroot bristlegrass	2.2	WPN [2]		
Panicum oligosanthes	Scribner's panicum	2.0	CPN	C3	
Cenchrus incertus	grassbur	0.9	WPN	C4	-11.5
Moss, unspecified		0.9	unkn		
Polypremum procumbens	polly-prim	0.7	WAN		
Eragrostis spectabilis	purple lovegrass	0.7	WPN	C4	-11
Unidentified		0.7	unkn		
Schizachyrium scoparium	little bluestem	0.7	CPN	C4	-14
Euphorbia cordifolia	heart-leaf euphorbia	0.7	WAN		
Quercus virginiana	live oak shoots	0.2	CPN		
Cyperus strigosus	false nutgrass	0.2	WPN		
Sida filicaulis	spreading sida	0.2	WPN [3]		
Diodia teres	poor Joe	0.2	WAN		
Portulaca umbraticola	wing-pod portulaca	0.2	unkn		
Froelichia gracilis	slender snake-cotton	0.2	WAN		
May, 1976 sample					
Commelina erecta	erect day-flower	1.6	WPN		
Panicum sphaerocarpon	round-seed panicum	1.4	CPN		
Unidentified		1.4	unkn		
Paspalum plicatulum	brownseed paspalum	1.1	WPN	C4	
Sporobolus indicus	smutgrass	0.9	WPI	C4	
Quercus virgin1ana	live oak shoots	0.7	CPN		
Vitis mustangensis	mustang grape	0.7	CPN		
Rhynchosia americana	American snoutbean	0.7	WPN		
Cassia fasiculata	partridge pea	0.7	WAN [4]		
Panicum hians	gaping panicum	0.4	WPN	C3	-26.0
Vernonia sp.	ironweed	0.4	WPN		
Ambrosia psilostachya	western ragweed	0.4	WPN [5]		
Croton capitatus	woolly croton	0.2	WAN		
Coreopsis nuecensis	crown coreopsis	0.2	WAN		
Gaura sp.	gaura	0.2	unkn		

(Table 1.5 continued on next page)

(Table 1.5 continued from previous page)

Taxon	Common name	Percent cover	Code*	Path	$\delta^{13}C$
May, 1976 sample (cont.)					
Oxalis sp.	wood-sorrel	0.2	unkn		
Cenchrus incertus	grassbur	0.2	WPN	C4	-11.5
Croptilon divaricatum	scratch-daisy	0.2	WAN		
Sida filicaulis	spreading sida	0.2	WPN[3]		
Conyza canadensis	horse-weed	0.2	WAN		
Schrankia uncinata	catclaw sensitive brier	0.2	WPN		
Euphorbia dentata	toothed spurge	0.2	WAN		
Pilea pumilaclear	weed	0.2	WAN		
Limnodea arkansana	ozarkgrass	0.2	CAN	C3	-28.1

* CODE: C = cool season, W = warm season; A = annual, P = perennial, I = introduced, N = native, unkn = unknown; [1] *E. secundiflora* ssp. *oxylepis*; [2] *Setaria gracilis, S. parviflora*; [3] *Sida abutifolia*; [4] *Chamaecrista fasciculata*; [5] *Ambrosia cumanensis.*

The "potential plant community" listed for the Gravelly range site habitat in the DeWitt County soil survey (Miller 1978:46) is

> 55 percent little bluestem; 15 percent indiangrass, switchgrass, beaked panicum, and purpletop; 10 percent brownseed paspalum, side-oats grama, purple lovegrass, and other grasses; 10 percent post oak and blackjack oak; 5 percent hawthorns, American beautyberry, and greenbrier, and 5 percent lespedezas, tickclover, bundleflower, snoutbean, and annual forbs.

This may be a better estimate of the presettlement ground cover in the post oak belt than the actual quantitative studies of the present ground cover done by Espey, Huston & Associates. Except for the grasses noted above, these natives are warm-season grasses (that is, they are perennials, but mature in the warm part of the year).

3) *Brushland*. Brush consists of over 90% huisache (*Acacia farnesiana*, 381 per hectare), mesquite (*Prosopis glandulosa*, 210 per hectare), and post oak (133 per

hectare), along with some live oak, yaupon, and coma. About 12% of the ground cover is litter. Ground cover is mostly knotroot bristlegrass (about 44-45% of ground cover), *Paspalum*, *Panicum*, and ragweed.

4) *Grassland*. Grazing of grassland in the power plant project area has artificially increased its species richness. Johnston (1963:460) notes the same effect for prairies farther south on the coastal plain. Dominants include smutgrass, Bahia grass, knotroot bristlegrass, thin paspalum, Scribner's panicum, round-seed panicum, oldfield three-awn, pan American balsamscale, brownseed paspalum, Kearney three-awn, lovegrass, and various forbs, mostly annual (Tables 1.6, 1.7). Here again, the grasses are mostly annuals. Litter ranges from about 4-6%; bare ground ranges from about 5-23%.

5) *Bottomland forest*. The closed-canopy floodplain forest habitat was essentially removed from the Berger Bluff catchment in the early Holocene. The Espey Huston baseline study included one "bottomland forest" stand, but it is located three meters above the creek bed (Espey, Huston & Associates 1976:2-9) on what is evidently a narrow post-Beaumont terrace remnant, on the west side of Coleto Creek about 800 m downstream the mouth of Turkey Creek (USGS Fannin quad). It is therefore better regarded as "terrace woodland," seldom flooded except in extreme flood events, and is not really the functional equivalent of the late Pleistocene/early Holocene floodplain forest.

Table 1.6. Ground Cover in Grassland I, Coleto Creek Power Plant Project (source: Espey, Huston and Associates 1976:Table 2-2; ground cover only, sorted by % cover, zero coverage taxa omitted).

Taxon	Common name	Percent cover	Code*	Path	$\delta^{13}C$
October, 1975, Grassland I					
Sporobolus indicus	smutgrass	32.3	WPI	C4	
Paspalum notatum	Bahia grass	15.0	WPI	C4	-12
Setaria geniculata	knotroot bristlegrass	7.3	WPN [1]		
Aristida oligocantha	oldfield three-awn	5.4	WAN		
Cynodon dactylon	Bermuda grass	5.4	WPI	C4	-13.4
Elyonurus tripsacoides	Pan Am. balsamscale	4.5	WPN		
Paspalum plicatulum	brownseed paspalum	3.5	WPN	C4	
Aristida longespica	Kearney three-awn	3.2	WAN		
Eragrostis oxylepis	lovegrass	2.2	WPN [2]	C4	
Ambrosia psilostachya	western ragweed	1.6	WPN [3]		
Panicum sp.	Panicum sp.	1.3	W?		
Sporobolus purpurascens	purple dropseed	1.3	WPN		
Sida filicaulis	spreading sida	1.0	WPN [4]		
Croptilon divaricatum	scratch-daisy	0.6	WAN		
Aster subulata	salt-marsh aster	0.6	WAN		
Acacia farnesiana	huisache	0.6	CPN [5]		
Palafoxia reverchonii	Reverchon palafox	0.6	WAN		
Galactia marginalis	milkpea	0.3	WPN		
Panicum hians	gaping panicum	0.3	WPN		
Diodia teres	poor Joe	0.3	WAN		
Polypremum procumbens	polly-prim	0.3	WAN		
Evolvulus sericeus	silky evolvulus	0.3	WPN		
Chloris cucullata	hooded windmill grass	0.3	WPN	C4	-15.9, -13.2
Cenchrus incertus	grassbur	0.3	WPN	C4	-11.5
Croton capitatus	woolly croton	0.3	WAN		
Phyla incisa	Texas frog-fruit	0.3	WPN		
Lechea san-saba	pinweed	0.3	WPN [6]		
Commelina erecta	erect day-flower	0.3	WPN		
Croton glandulosa	Lindheimer croton	0.3	WAN		
Quercus stellata	post oak	0.3	CPN		
Quercus virginiana	live oak shoots	0.3	CPN		
Eragrostis spectabilis	purple lovegrass	0.3	WPN	C4	-11

* CODE: C = cool season, W = warm season; A = annual, P = perennial I = introduced, N = native; [1] *Setaria gracilis, S. parviflora*; [2] *E. secundiflora* ssp. *oxylepis*; [3] *Ambrosia cumanensis*; [4] *Sida abutifolia*; [5] *A. smalli*; [6] *L. san-sabeana*.

Table 1.7. Ground Cover in Grassland II, Coleto Creek Power Plant Project (source: Espey, Huston and Associates 1976:Table 2-3; ground cover only, sorted by % cover, zero coverage taxa omitted).

Taxon	Common name	Percent cover	Code*	Path	$\delta^{13}C$
May, 1976, Grassland II					
Setaria geniculata	knotroot bristlegrass	10.6	WPN [1]		
Paspalum setaceum	thin paspalum	9.1	WPN		
Panicum oligosanthes	Scribner's panicum	9.1	CPN [2]	C3	
Diodia teres	poor Joe	8.6	WAN		
Croptilon divaricatum	scratch-daisy	8.2	WAN		
Panicum sphaerocarpon	round-seed panicum	7.7	CPN [3]		
Panicum sp.	Panicum sp.	5.3	W?		
Croton capitatus	woolly croton	3.8	WAN		
Rudbeckia hirta	brown-eyed susan	3.8	WPN		
Gaillardia pulchella	Indian blanket	2.4	WAN	C3	-29.0
Sida filicaulis	spreading sida	1.4	WPN [4]		
Stylosanthes viscosa	pencilflower	1.4	WPN		
Sporobolus indicus	smutgrass	1.4	WPI	C4	
Astranthium integrifolium	western daisy	1.0	CAN		
Cassia fasciculata	partridge pea	1.0	WAN [5]		
Oenothera laciniata	downy evening primrose	1.0	CPN		
Paspalum plicatulum	brownseed paspalum	1.0	WPN		
Xanthocephalum texana	broomweed	0.5	WAN [6]		
Sporobolus junceus	piney-woods dropseed	0.5	WPN		
Krigia occidentalis	western dwarf dandelion	0.5	CAN		
Commelina erecta	erect day-flower	0.3	WPN		
Unidentified forb	0.5	unkn			
Juncus marginatus	grass-leaf rush	0.5	WPN		
Quercus stellata	post oak	0.5	CPN		
Cyperus sp.	sedge	0.5	unkn		

CODE: C = cool season, W = warm season; A = annual, P = perennial I = introduced, N = native, unkn = unknown; [1] *Setaria gracilis, S. parviflora*; [2] *Dichanthelium oligosanthes;* [3] *Dichanthelium sphaerocarpon;* [4] *Sida abutifolia;* [5] *Chamaecrista fasiculata*; [6] *Gutierrezia texana.*

The trees are mostly pecan, anacua, and sugarberry (*Celtis laevigata*), along with a few winged elm, sycamore, and red mulberry. Small numbers of blackbrush, yaupon, bois d'arc, wafer ash, gum bumelia, Mexican buckeye, and mustang grapevine are found in the understory.

PALEONTOLOGICAL CLUES TO PAST FLORA

Undated Quaternary fossils of both grazers (mammoths and *Bison antiquus*) and browsers (mastodons) have been found in or near the catchment, suggesting it has long supported some mixture of woodland and prairie. One of the earliest records is by Berlandier, who reported in 1829 that

> It was in this area on the banks of the Coleto that a resident of Goliad found a molar of a mastodon. Although it was in three pieces it was taken to Dr. Chowell, from whom I learned these details. A few years previously in the same place that same resident found a tooth which, by the description he gave of it, could have belonged to some large species of Anoplotherium (Berlandier 1980:552).

Howard (1931:33) reported that "the remains of a mastoden [sic] have been taken from the banks of Caleta Creek [sic], eight miles West-Southwest of Victoria." McReynolds (1981:29) reports a mammoth tooth from deposits on the south side of Perdido Creek near its junction with Coleto Creek (now under the reservoir). Figure 1.21 shows a *Bison antiquus* skull found by Sonny Welsch on Eighteenmile Coleto Creek, near Weesache. The unconfirmed presence of mastodon is interesting, since these animals are usually interpreted as browsers living in wooded or shrubby habitats.

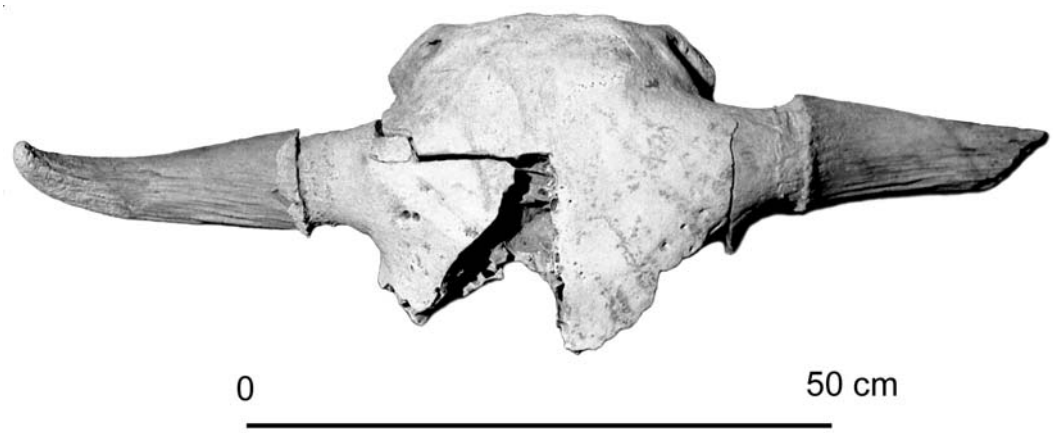


Figure 1.21. *Bison antiquus* Skull from Welsch Fossil Locality. Brain case with horn cores, discovered on Eighteenmile Coleto Creek, near Weesache.

Post oak dendroecology

David Stahle analyzed a set of 42 tree-ring chronologies from the south-central US for his dissertation research on frost-damaged rings (Stahle 1990); a subset of nine of these is used by Stahle and Cleaveland (1988) for their research on drought recurrence. The southernmost of these sites (site 38) is a stand of post oaks (*Quercus stellata*) located on the southwest side of Coletoville Road and on the northeast side of Turkey Creek, near the Flume 3 right-of-way (Fig. 1.22). The location is on Lissie Formation sediments about 2.3 to 3.1 km southwest of Berger Bluff (David Stahle, personal communication; Stahle *et al*. 1985:103). The 330-year chronology for this stand, sampled in March 1983, extends from 1682 to 1982. Only 0.13% of the rings in this set of trees were frost damaged (compared to over 4% in interior parts of Texas; Stahle 1990:Table 1). Generally speaking, the distribution of frost damage corresponds fairly well to continentality as mapped in Fig. 1.13.

Figure 1.22. Post Oak Woodland. Looking south at mature post oak woodland on Lissie Formation southwest of Coletoville Road, Goliad County. This stand was cored in 1983 by David Stahle. Trees in this view are more closely spaced than is typical for much of the surrounding area.

Figure 1.23 shows the tree-ring index for post oaks at this site, along with a couple of smoothing methods applied to the original data. A spectral density plot (not shown) of the data does not appear to show any noticeable frequency peaks, but a lowess-smoothed plot of the data (Fig. 1.24) shows what appear to be a series of surprisingly regular peaks in the index. Intervals between successive peaks range from roughly 11-38 years (visually estimated). In this plot, the Y axis is the tree-ring index, shown on a logarithmic scale. The tree-ring index is a measure of ring width that omits effects such

as growth that slows as a tree ages. Wide rings in these trees are produced by cool, moist growing conditions, while narrow rings are produced by warm, dry conditions (Stahle 1990:32).

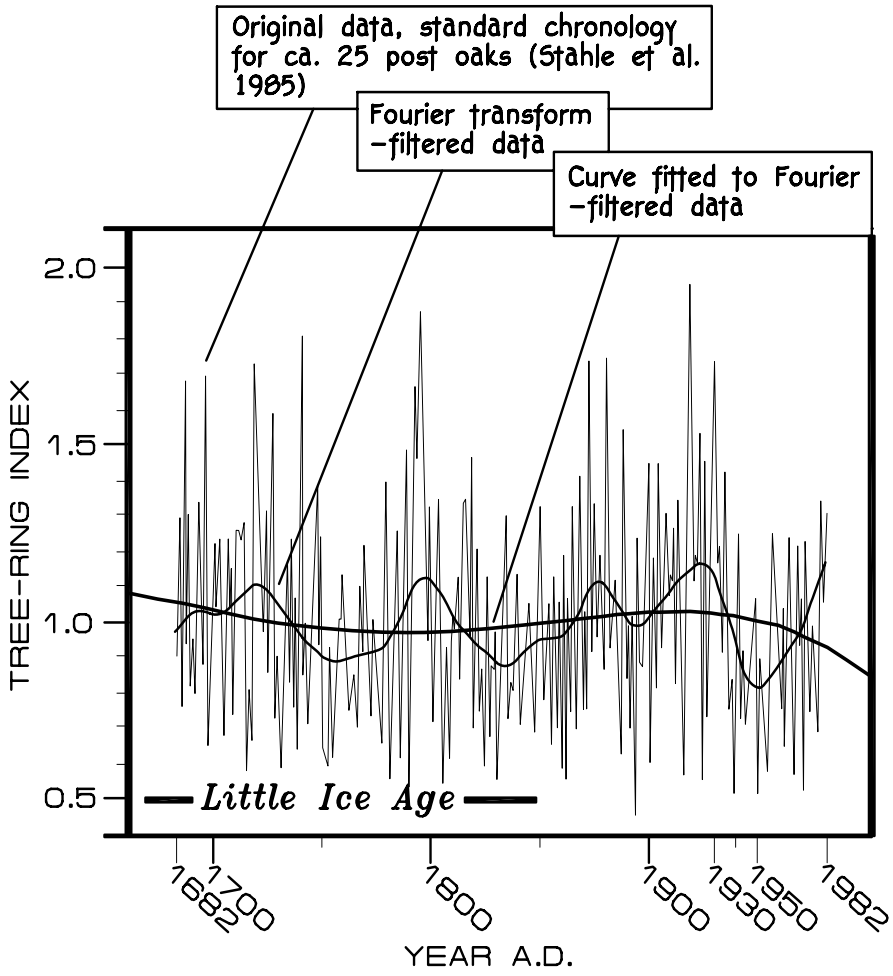


Figure 1.23. Tree-Ring Index, Post Oaks at Coleto Creek Power Plant. Data from Stahle *et a*l. (1985), covering the period 1682-1982.

Spectral analysis of the Palmer Drought Severity Index as estimated from the subset of nine chronologies revealed one statewide frequency peak at 2.3 years and peaks

at 17.5 and 20 years for the Yegua Creek, Lavaca River, and Coleto Creek sites (Stahle and Cleaveland 1988:70).

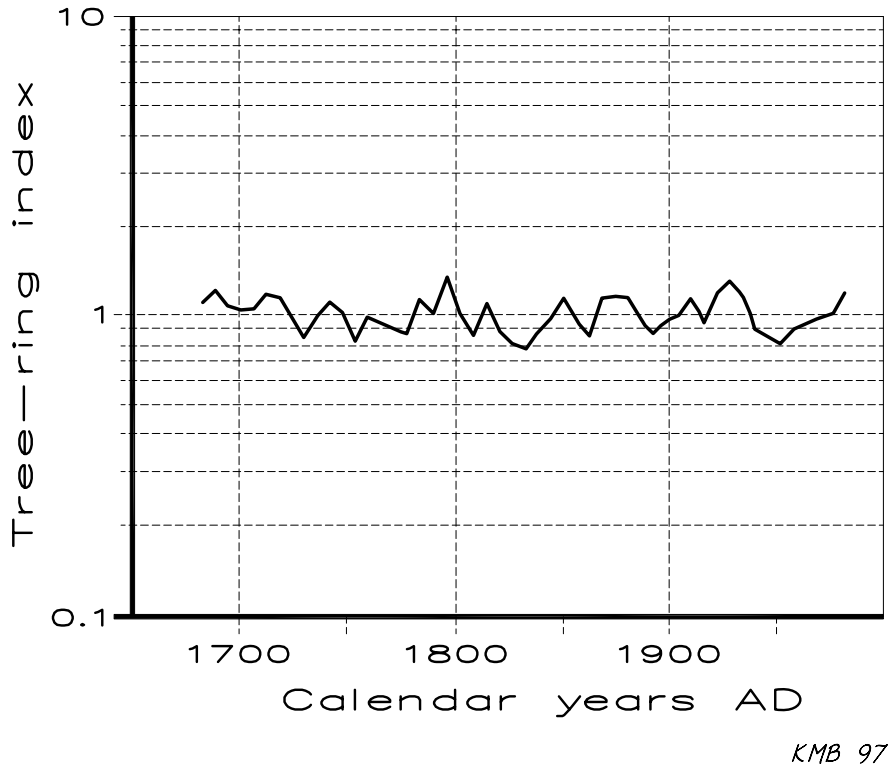


Figure 1.24. Lowess-Smoothed Tree-Ring Index, Post Oaks at Coleto Creek Power Plant. Same data shown in previous figure, with lowess weighting. Peaks of index indicate cool-moist periods. Note logarithmic Y axis.

The tree-ring data do not help explain cyclic deposition at Berger Bluff, for the climatic cycles seen in the post oak rings are too brief to be visible in the geoarcheological record. Nor do they help date the late Holocene incision of the post-Beaumont terrace, an event that probably begins anywhere from decades to centuries before the beginning of the tree-ring record. Rather, the chief value of the tree-ring data is that they demonstrate that evidence of cyclic climate change can be detected in the

biological record of the Coleto Creek basin, even though the area now experiences substantial climatic buffering by the Gulf of Mexico (although the frost ring counts clearly demonstrate that the chronologies are not nearly as sensitive as those from the interior parts of the state). In summary, for the late Holocene the paleoclimatic record appears somewhat climatically insensitive, but not entirely silent.

REGIONAL GEOLOGIC SETTING

The Gulf Coastal Plain of Texas is a broad, flat plain with low relief, consisting of sediments which crop out in imbricated narrow bands parallel to the present coastline and which become progressively younger toward the Gulf. Within the *Berger Bluff catchment basin* (that is, that part of the Coleto Creek drainage basin lying upstream from Berger Bluff) these formations range in age from Miocene to late Pleistocene; sediments younger than these are confined to stream valleys. Since the late Tertiary as well as Quaternary sediments contain fossilized plants and animals that are in some instances similar to modern species, all the formations in the catchment basin are potential contributors of relict life forms to the Late Pleistocene or Holocene sediments at the site. Special care must be taken in the identification of snails, vertebrates, and fossilized plant parts to distinguish potential environmental "background noise". As an example, freshwater sponge spicules in the bench deposits may be at least partly derived from older Lissie deposits upstream, since identical but less fragmented spicules have been found in soil samples from the base of the Lissie cutbank.

Many of the Gulf coastal plain formations form low cuestas as a result of cross-sectional resistance to erosion, and these create water gaps which inhibit lateral migration of streams at the knickpoints. Coleto Creek itself heads on the Gulf-facing flank of the

Oakville Escarpment but has not cut through it. This escarpment appears as a conspicuous ridge on the horizon when approached from the west on Highway 119. Achalabhuti (1973:44) also recognizes a Goliad Cuesta in the catchment basin, but it seems less well defined. Elevation in the Berger Bluff catchment varies from about 570 feet (175 m) on ridges at the head of the catchment to about 75 feet (23 m) for the bed of the creek at the site.

Since the Pleistocene/Holocene sediments at Berger Bluff rise to nine meters above the creek bed, we might ask whether some or all of this elevation may be due to postdepositional uplift, either on a regional or a local scale. Several considerations argue against it. First, the Coleto catchment lies in an area that has been generally subsiding during the Quaternary, as a result of isostatic adjustment to sediment loading or to differential loading caused by eustatic sea level changes in the Gulf (see Higgins 1969). It is positioned well to the downwarped side of all of Winker's estimates of the position of the hinge line for deformation of the Beaumont surface (Winker 1979:Fig. 44). Secondly, the age of the deposits which are of concern here is probably less than the amount of time required for significant deformation. Third, while there is a fault scarp passing near the site, the site lies on the *downthrown* side of the scarp (Fig. 1.25).

CATCHMENT BASIN GEOLOGY

The *Berger Bluff catchment* is defined here as that part of the Coleto Creek basin lying upstream from Berger Bluff — in other words, the maximum area that could have contributed sediment to the deposits at Berger Bluff. It is a leaf-shaped area (Fig. 1.26) about 60 km long, 29 km wide, oriented northwest-southeast, and covers an area of 1011.77 square kilometers, heading in Karnes County on the southeastward-sloping face

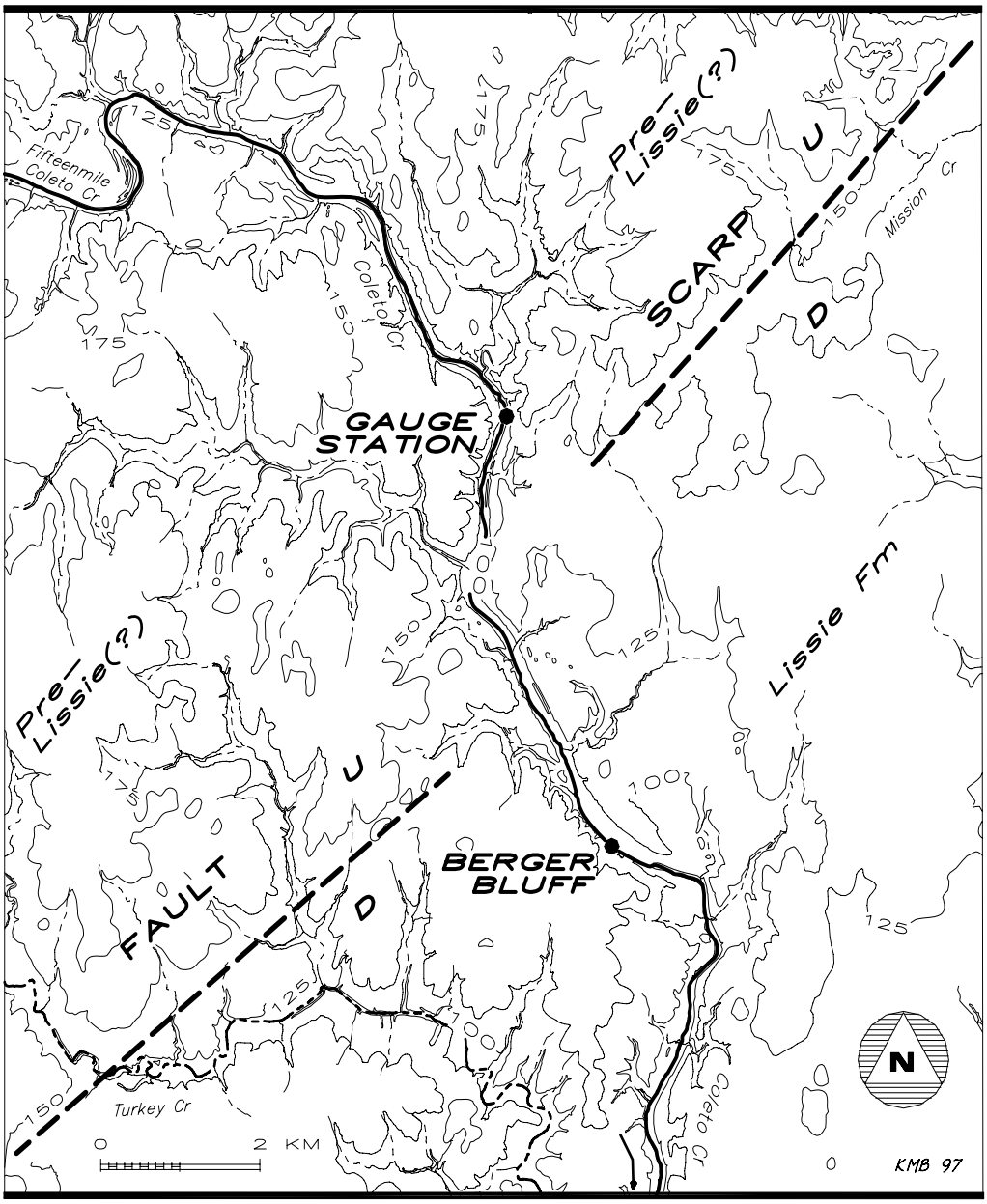


Figure 1.25. Location of Fault Scarp North of Berger Bluff. Topography from USGS Schroeder quad, showing uplifted and dissected pre-Lissie (?) surface postulated by Winker (1979) to the north, and downthrown Lissie Formation surface to the south, separated by poorly defined and discontinuous SW-NE trending fault scarp, 2.3 km of more upstream from Berger Bluff. Highway 622 discharge gauging station (now discontinued) is also shown. Contour interval 25 feet (7.6 m).

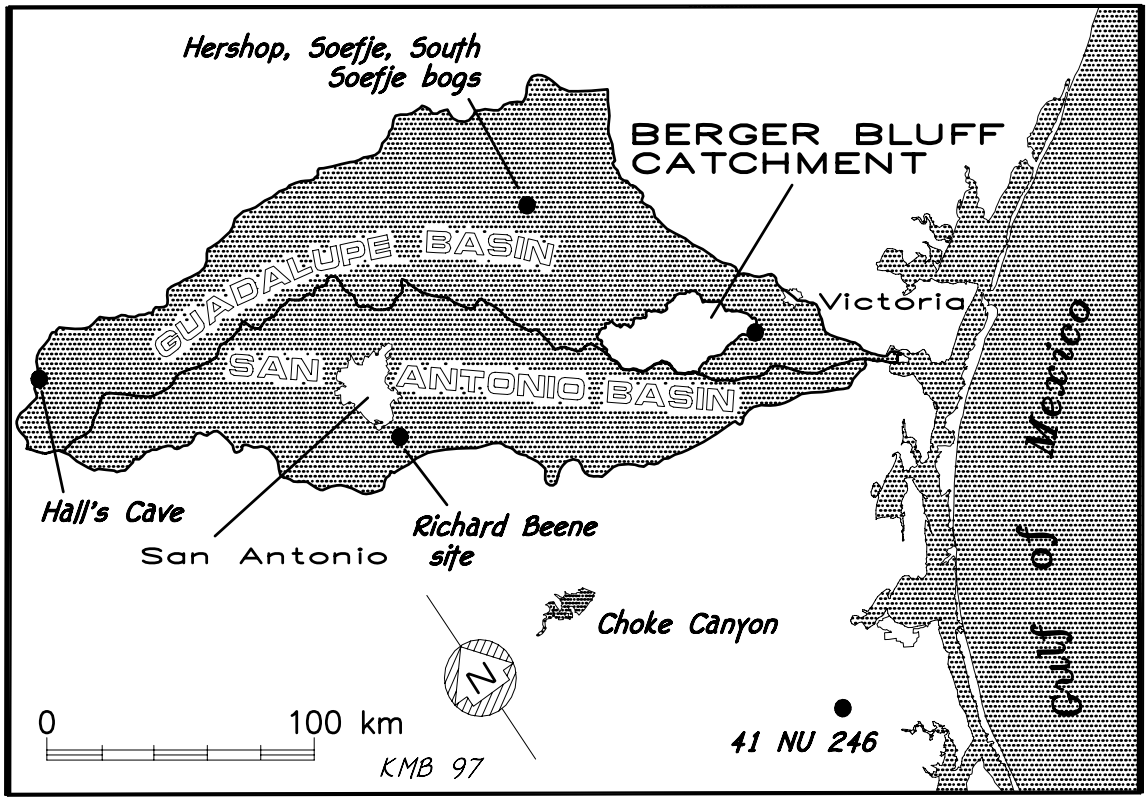


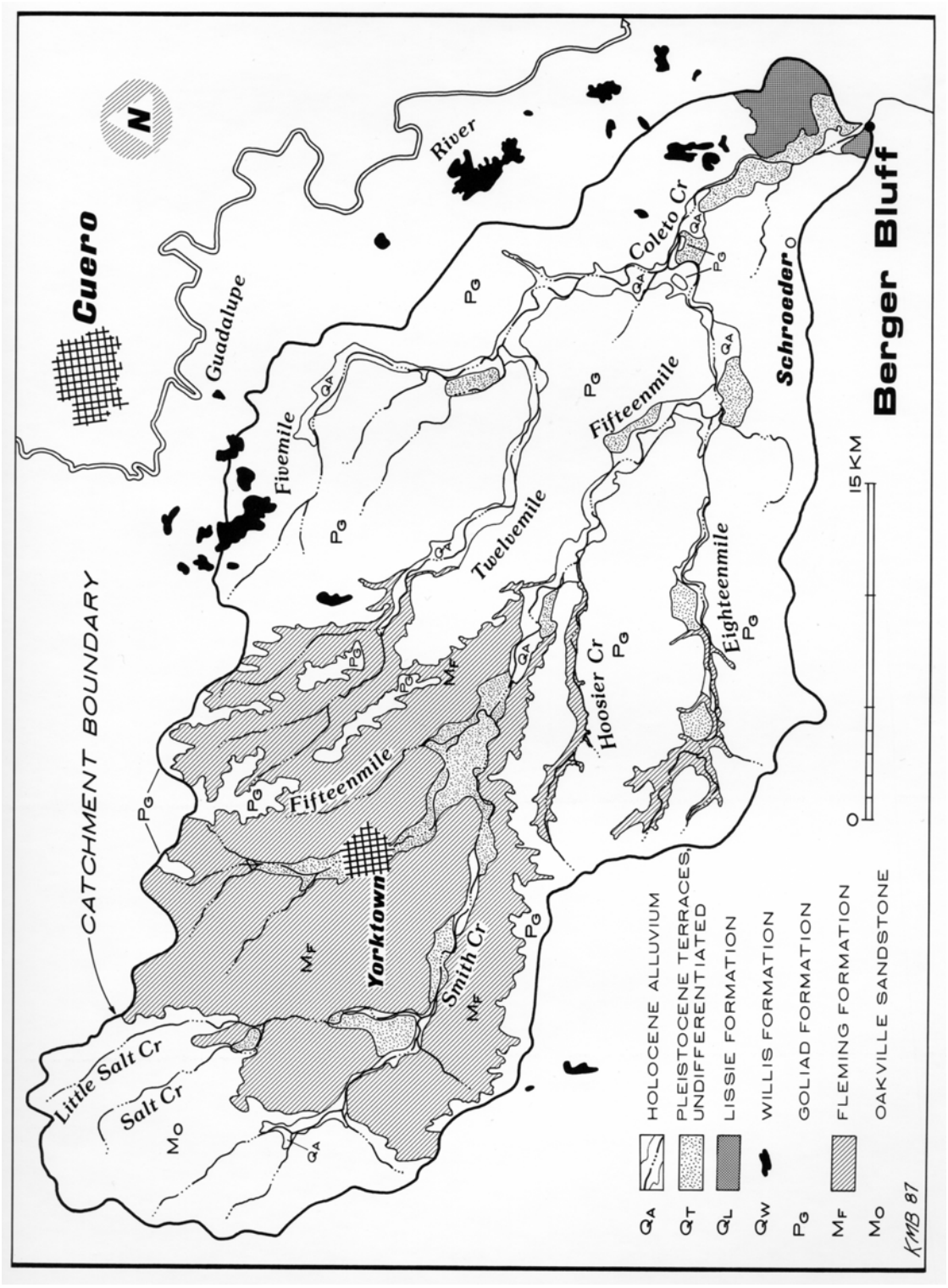
Figure 1.26. Geographic Position of the Catchment. The Berger Bluff catchment is located near the distal end of the Guadalupe River basin; the San Antonio River basin joins shortly before both discharge into San Antonio Bay. Berger Bluff is represented by a dot at the southeast end of the catchment. Other dots indicate important paleoenvironmental sites in or near these basins; note rotated map orientation.

of the Bordas-Oakville Escarpment. The maximum drainage length is 89 river kilometers (55 miles) from Berger Bluff to the head of Salt Creek in Karnes County. It represents less than 7% of the Guadalupe River basin, which covers 15,403 square kilometers. Together with the San Antonio River basin (10,787 square kilometers), the two river basins cover an area of 26,190 square kilometers at present, though the area was somewhat larger in the early Holocene (see below). In terms of Schumm's (1977:Fig. 1-1) three fluvial zones, Berger Bluff lies in Zone 2, the sediment transfer zone. It is

important to remember that, because Berger Bluff lies near the distal end of the Coleto Creek drainage, the climatic events that may have affected sediment deposition at the site were primarily those taking place in DeWitt County, generally around Yorktown. Most of the Berger Bluff catchment consists of fairly easily eroded, sandy Miocene sediments. The major drainages in the catchment are Eighteenmile, Fifteenmile, Twelvemile, and Fivemile Coleto Creeks. As defined by the *Geologic Atlas of Texas* (Beeville and Seguin sheets; Barnes 1974, 1975) the Oakville Sandstone (Miocene), Fleming (Miocene), Goliad (Miocene or Miocene/Pliocene), and Lissie formations (Pleistocene) crop out as a succession of increasingly younger units proceeding downbasin toward Berger Bluff. The Lissie Formation as defined both by Winker (1979) and the *Geologic Atlas* includes the Montgomery and Bentley terraces (recognized as separate units farther up the coast but considered indistinguishable here). There are also isolated very small remnants of the Willis Formation, early Pleistocene or late Pliocene stream gravels occurring as small, patchy deposits chiefly on the divide between the Coleto and the Guadalupe River, overlying the Goliad Formation. Only about five and a half square kilometers of the basin are covered by the Willis Formation, but the larger deposits are indicated in Figure 1.27 both as a potential source of cobble chert for making stone tools and as a possible source of coarse lag gravels in present-day Coleto Creek. Another, later Pleistocene high gravel deposit occurs as a single isolated remnant just outside of the catchment boundary northwest of the head of Salt Creek, in Karnes County. It has been heavily quarried for road metal, but enough gravel remains to demonstrate a unique lithology very reminiscent of reworked Ogallala gravels in east Texas. In the stream valleys are situated the two youngest units, post-Beaumont terrace deposits and very recent packages of Holocene alluvium. Figure 1.27 shows that, in terms of proximity to the site, the Lissie terrace is the most important source of alluvium for the site and the Oakville Sandstone

the least important. However, in terms of outcrop area, the ranks are somewhat different. The Goliad Formation, with about 509 km^2 of exposure occupies the first rank, and the Lissie with about 12 km^2, the next to last rank (Fig. 1.28)

Figure 1.27. Geology of the Berger Bluff Catchment *(following page, landscape orientation).* Shown is the leaf-shaped drainage area contributing sediment to Berger Bluff. Relative areas covered by the different formations are indicated in the next figure. Willis Formation deposits near but outside the catchment boundary are also shown. Goliad Formation (white area with P_G symbol) is now regarded as Miocene rather than Pliocene (source: Geologic Atlas of Texas, *Seguin* (1974) and *Beeville-Bay City* (1975) sheets.


CATCHMENT BOUNDARY
Cuero
N
Guadalupe
River
Fivemile
Twelvemile
Fifteenmile
Yorktown
Smith Cr
Hoosier Cr
Eighteenmile
Coleto Cr
Schroeder
Berger Bluff
Little Salt Cr
Salt Cr
0
15 KM
QA HOLOCENE ALLUVIUM
QT PLEISTOCENE TERRACES, UNDIFFERENTIATED
QL LISSIE FORMATION
QW WILLIS FORMATION
PG GOLIAD FORMATION
MF FLEMING FORMATION
MO OAKVILLE SANDSTONE
KMB 87

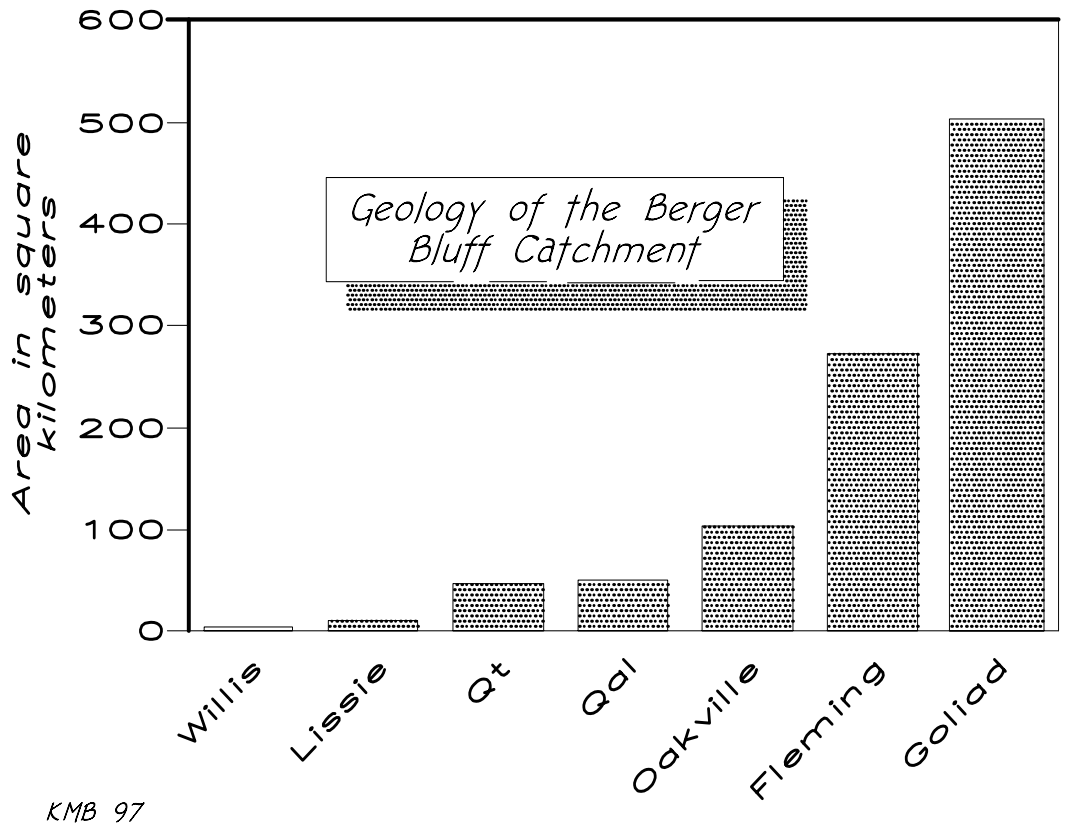


Figure 1.28. Relative Exposures of Different Geologic Formations in the Berger Bluff Catchment. Sizes of outcrop areas shown in Figure 1.27 are diagrammed here. *Qt* indicates undifferentiated Pleistocene terrace deposits; *Qal* indicates Holocene alluvium.

The cuesta-forming *Oakville Sandstone* occupies the head of the catchment basin in an area drained by the heads of Salt and Thomas creeks, and consists of light gray medium-grained calcareous sandstone and yellowish-gray calcareous clay. Chert and quartz gravel, vertebrate fossils, and redeposited Cretaceous invertebrates are also present (Geologic Atlas of Texas, Seguin sheet). Vertebrates include softshell turtle, alligator, extinct Miocene camels, horses, rhinoceroses, and a mastodon (Sellards, Adkins, and Plummer 1932). Galloway and others (1986:Fig. 2) list its age as about 19-23.5 million years. Tedford and others (2004:Fig. 6.2) list a slightly longer span, about

16.5-24.5 million years ago. Ragsdale (1960:26) reports grain size means from the Oakville in Gonzales County ranging from 1.08 to 2.51 phi, with standard deviations ranging from 0.57 to 0.72.

The *Fleming Formation* (formerly Lagarto Clay) occupies an area around Yorktown drained by Yorktown and Smith creeks and may have been a major source of the clay fraction in the Berger Bluff sediments. It consists of calcareous clay and yellowish-gray to light gray, calcareous medium to coarse-grained sandstone (Seguin sheet). It is similar to the Oakville, but more clay-rich. Vertebrate fossils, including Miocene quadrupeds (see MacFadden and Skinner 1981; Prothero and Sereno 1982; Prothero and Manning 1987), microvertebrates (Albright 1996; Schiebout and Ting 1998), salamanders, anurans, crocodilians, gar, drum, turtle, lizards, snakes (Holman 1977), occasional land invertebrates, and redeposited Cretaceous fossils occur in the sediments. Galloway *et al.* (1986) list it as early Miocene. Tedford and others (2004:Fig. 6.2) list it as early to Middle Miocene, perhaps about 12.5-24.5 million years before present. Sellards, Adkins and Plummer (1932:746) report modal grain size chiefly in the 0.0 to 3.0 phi range.

The *Goliad Formation*, covering an area of about 509 km^2, occupies nearly the entire downstream half of the catchment, an area drained by Fivemile, Twelvemile, Fifteenmile, and Eighteenmile Coleto creeks and Hoosier Creek. The Goliad sandstone also forms several ridge-capping erosional outliers to the northeast of Yorktown. Its updip erosional face is sometimes referred to as the Bordas Escarpment. The Goliad consists of pink or green clay, medium to coarse-grained sand and sandstone, conglomerate consisting of gravel in a caliche or sandy matrix, and marl or limestone. At

the Highway 622 crossing over the Coleto, five kilometers upstream from Berger Bluff, a section of the Goliad (now drowned by the lake) consists of two to three meters of white to gray sandstone overlain by white, pink and red sandy marl with caliche nodules (cf. Achalabhuti 1973:47). The Goliad is actually a heterogeneous, poorly defined unit that has served as a catchall term for calcareous strata above the Lagarto clay and below the Lissie Formation. Sellards, Adkins, and Plummer recognize three members, *Lapara*, *Lagarto Creek*, and *Labahia*, with gravel more common in the lower strata; they list the overall composition of the Goliad as about 80% sand, 5% gravel, 10% clay, and the remainder calcium carbonate. Modal grain size is about 2.0 to 3.0 phi (Sellards, Adkins, and Plummer 1932:758). It is roughly 5-10 million years old. Extinct horse (Hulbert 1987), rhinoceros, camel, canid, cervid, antilocaprid, and bird bones have been found in the Goliad. A more recent study of the formation by Hoel (1982) suggests that the members recognized by Sellards, Adkins, and Plummer have no regional significance. According to her, the Cuero and Eagle Lake fluvial systems (recognized in subsurface Goliad deposits chiefly on the basis of electric well logs) are characterized by channel fill facies with poor to moderately well sorted medium to coarse sand and pebbly sand and minor components of fine sand, silt and clay; crevasse splays are characterized by medium to fine sand and silt with minor components of coarse sand, pebbly sand, and clay; and floodplain facies are characterized by mottled red and white calcareous clays with white caliche nodules and stringers (Hoel 1982:79-87). Arrendondo and Thomann (1996:285-287) also provide a detailed description of Goliad Formation petrology. Although the Geologic Atlas of Texas originally assigned the Goliad Formation to the Pliocene, Hoel (1982:Fig. 7) assigns the basal part to the Miocene, and regards the entire formation as stratigraphically equivalent to the Willis Formation (a relationship not recognized by other stratigraphers, and probably not valid). Late Miocene climate is

thought to have been generally arid and strongly seasonal, characterized by widespread expansion of C4 grasses and high rates of animal extinctions.

This unit is represented at Berger Bluff by exposures of white, friable to well indurated, calcareous cemented sandstone in the ravine next to the site and by caliche and well indurated sandstone bedrock exposed in backhoe trenches in area B. A few samples have been disaggregated and analyzed for grain size distribution. A more detailed description will be provided in a later chapter.

The Goliad Formation is an important part of the Berger Bluff story. Although parts of the unit are well cemented, much of it is so friable and coarse-grained that it is easily erodible. As a result Coleto Creek is much more deeply and narrowly incised (about 14 meters at Arnold Road, for example) during its passage across the Goliad Formation than either upstream or downstream. Sediment production rates from the Goliad outcrop are very high, unless the surface is well stabilized by vegetation. The Goliad Formation is also an important aquifer, as will be seen in later chapters.

The *Willis Formation*, as mentioned before, is a Pleistocene (or Pliocene, according to some interpretations; Winker 1979:104, Hoel 1982:Fig. 7) fluviatile deposit that is insignificant in areal extent, occurring only as patchy remnants on the Coleto-Guadalupe divide, overlying the Goliad Formation. It has sometimes been equated with the Citronelle Formation of the Gulf coast between Mississippi and Florida, but the Citronelle Formation is evidently late Pliocene (about 2.7-3.4 million years old; Otvos 1998). It is of importance, however, as a possible source of cobble-sized chert, quartzite or other rocks. Collins (2002) provides a thorough discussion of this chert source, and

Glascock (2002) has characterized its chemical composition. It also includes fine to very coarse sand, silty yellow-gray to mottled red and light gray clay with iron oxide concretions locally abundant. Willis deposits frequently support post oak motts. The formation equates in part with a pre-Lissie terrace surface

The remaining stratigraphic units in the Coleto Creek catchment — Lissie, Beaumont, and post-Beaumont — are exposed in the immediate vicinity of Berger Bluff and will be described in considerably more detail in a later chapter. The origin of the Pleistocene units has been summarized by Winker:

> The lower Texas coastal plain is essentially a clay-rich alluvial plain made up of coalescing low-gradient fans. The Beaumont alluvial plain onlaps an older surface (Lissie) which was tilted seaward prior to Beaumont deposition; the Lissie in turn onlaps remnants of older surfaces. During Beaumont deposition, each major coastal river deposited a branching network of meanderbelt sand-bodies by repeated avulsions...(Winker 1979:vi). Smoothing of the shoreline by waves resulted in deposition of strike-oriented sand bodies in interdeltaic bights (Winker 1979:150).

Overbank muds fill the interfluves.

The *Lissie Formation,* although covering only about twelve km^2 of the catchment, lies immediately upstream from Berger Bluff, extending almost as far as the Highway 622 bridge, and because of its proximity to the site can be expected to have been a major contributor of sediment. Comparisons of grain size for the Berger Bluff sediments and two stratigraphic sections in the Lissie terrace just upstream from the site will be presented later. The distinctively pink to red, iron and manganese-rich Lissie sediments consist of sand, silt, and clay, with some gravel; zones of caliche nodules occur in the cutbank near the site and elsewhere in the formation. Winker (1979:34) estimates the Lissie to be between 0.4 and 1.4 million years old.

The *Beaumont Formation* encloses the post-Beaumont sediments across the creek from Berger Bluff, but presumably contributed no sediment to the site. Winker (1979) estimated the age of the Beaumont Formation at 12,000-130,000 BP; radiocarbon assays on the equivalent Prairie Formation in Louisiana range from 23,080 RCYBP (or early Late Glacial Maximum; Birdseye and Aronow 1991) to more than 50,000 RCYBP. More recent optically stimulated luminescence (OSL) dates summarized by Otvos (2005:Table 4) range from 27,900 ± 2500 to about 135,000 calendar years BP (with a few scattered dates up to 194,000 BP). These deposits were formed during a period when sea level lay below its present level, rising and falling, but generally dropping as the polar regions became increasingly glaciated (Lambeck, Esat, and Potter 2002:Fig. 2, a). Fluvial facies consist of fine-grained meanderbelts separated by overbank clays. Vertebrate fossils include giant ground sloth (*Eremotherium* sp., Elsik 1986), fish, snakes, aquatic snails (*Amnicola limosa, Cincinnatia cincinnatiensis, Planorbella trivolvis*) and freshwater mussels (*Amblema, Leptodea, Toxolasma*; Aronow, Neck and McClure 1991).

In addition to the stratigraphic units already mentioned, there are about 101 km^2 of creek alluvium within the valleys of Coleto Creek and its tributaries upstream from Berger Bluff. About 53 km^2 represents modern alluvial fill in temporary storage by the fluvial system, chiefly sand with localized deposits of cobble-sized chert, petrified wood, and quartzite. This fill presumably postdates the Berger Bluff deposits. The remainder, 48 km^2, consists of Quaternary terrace deposits (probably mostly post-Beaumont, perhaps partly contemporaneous with Berger Bluff deposits).

DESCRIPTION OF THE SITE

Although written in the present tense, the following is a description of the site and its surroundings as they appeared before inundation by the reservoir.

Northeast-facing Berger Bluff rises nine meters above the bed of Coleto Creek, to an elevation of about 100 feet (30.5 m) above mean sea level (Fig. 1.29). Back from the bluff edge, the sloping, eroded surface of the post-Beaumont terrace continues to rise gently another four and a half meters in height to a low, rounded hill, underlain by Goliad marl and sandstone bedrock, roughly a hundred meters back from the bluff edge. This area of the site, designated 41 GD 30B, is partly wooded and partly covered with pasture grasses. The area next to the bluff edge (41 GD 30A) is covered with a thick anaqua grove in which hackberry, persimmon, and brazilwood trees can also be found. Mustang grapevines festoon the bluff edge and anaqua trees.

Bordering the site to the northwest is a narrow, deep ravine (Fig. 1.30, with its mouth shown near the number "1") which has cut down, through Goliad sandstone bedrock, to about nine meters below the crest of the hill. This ravine appears to be a very old erosional feature, probably predating all of the post-Beaumont deposits. In the bottom of the ravine, west of the site, is a small permanent spring, a pool of water a few meters across, bordered by cattails (*Typha* sp.; Fig. 1.31). Fed by groundwater emerging from an aquifer in the Goliad Formation, the spring — or others like it — is evidently as old as the ravine itself and may well be one reason why Berger Bluff has been so persistently occupied throughout prehistory. It was also the carbonate-laden groundwater from this

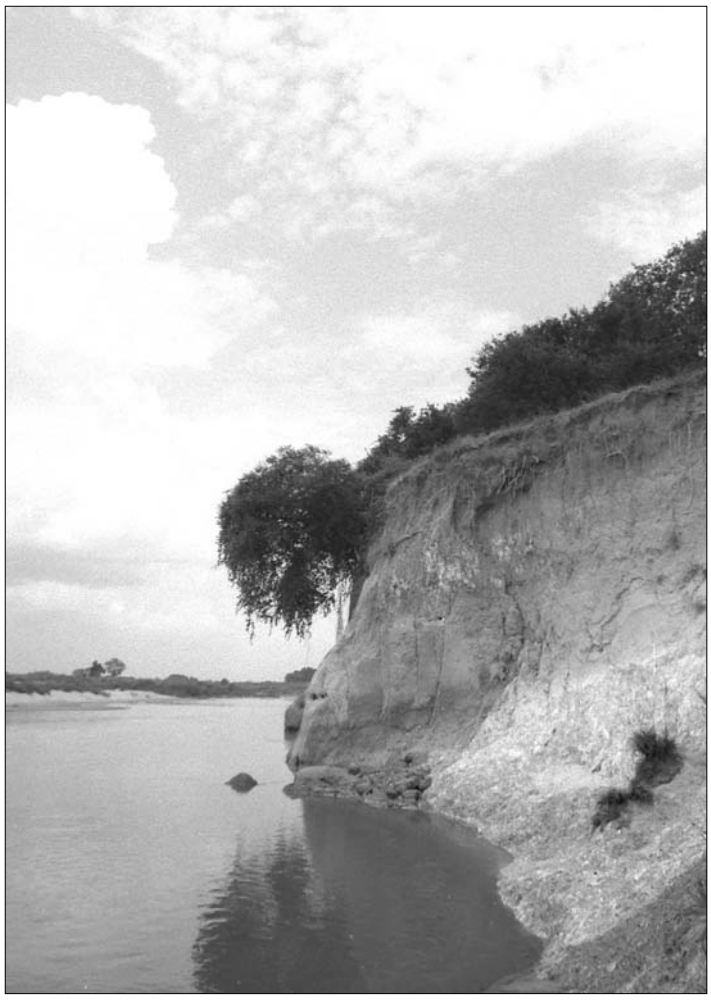


Figure 1.29. Berger Bluff. Looking downstream (southeast) from near the ravine mouth. Bench area is out of sight behind foreground prominence. White area at lower right is buried Goliad Formation erosional remnant; overlying sediments are post-Beaumont (photo taken in summer of 1979).

Figure 1.30 *(following page)*. Contour map of Berger Bluff Environs. Contour interval two feet (source: URS/Forrest and Cotton, Coleto Creek project maps, sheets 131 and 140, based on aerial photography flown July, 1974). Key: 1, 2 = location of Lissie terrace profiles; 3 = bench area of Berger Bluff. Profile 1 is just upstream from ravine mouth. The line A-B is the section line used to draw Figure 1.33, while the small letters A and B at 41 GD 30 represent areas A and B of the site. Vertical hash marks are backhoe trenches drawn to scale (including two trenches at 41 GD 31). The contemporary spring (see Figure 1.31) is a small dot (unlabeled) in the ravine just west of Area B.

For legibility, the label for 41 GD 31 is placed on the sandbar north of the site, but the site is located along the cutbank on the south side of the creek. The circled area south of 41 GD 31 is a surface concentration of patinated chipping debris lagged atop the terrace scarp. Note the smooth nature of the post-Beaumont sediments on the north side of the creek and the much greater dissection of the older Lissie Formation deposits on the south side of the creek.

FLOOD CHUTE
SANDBAR
UPPER POST-BEAUMONT TERRACE
SANDBAR
LISSIE TERRACE
LISSIE TERRACE
UPPER POST-BEAUMONT
GD 30
GD 31
Colcito Creek
KMB 95
Magnetic
N
0
200 M

Figure 1.31. Contemporary Spring in Ravine. Looking northeast at spring in ravine bed (now flooded by reservoir); note cattails and floating filamentous algae.

spring (or, more probably, another one like it located farther down the ravine) which saturated the bench strata as they accumulated, producing the calcareous cement which binds them. The ravine cuts headward about 400 meters into the Lissie sediments and underlying Goliad bedrock. Good exposures of tabular bedded sandstone, clay and marl can be seen in the walls of the ravine, separated by an erosional contact from the overlying Lissie sediments, which near the contact sometimes incorporate gravels or other clasts eroded from the bedrock. The headward part of the ravine is bedrock floored, and several wet weather seeps occur there (Fig. 1.32).

As it nears Berger Bluff, Coleto Creek swings southeastward in a broad, gently curving arc that allows the creek to cut into the base of the bluff over a long reach. At present, the Coleto is cutting downward and shifting its channel southward along this reach, and has probably been doing so for some time. It is perhaps partly because of this southward-and-downward movement that the Goliad County side of the creek has a steep cutbank, while the Victoria County side slopes gradually down to the creek bed (Fig. 1.33). The present cutbank corresponds closely to the scarp representing the maximum southwestern limit of Beaumont age valley widening. The Beaumont surface is about 2.5 km across in the vicinity of the site.

Figure 1.32. Knickpoint in Ravine. Looking headward (south) at Goliad sandstone beds forming floor and knickpoint in ravine.

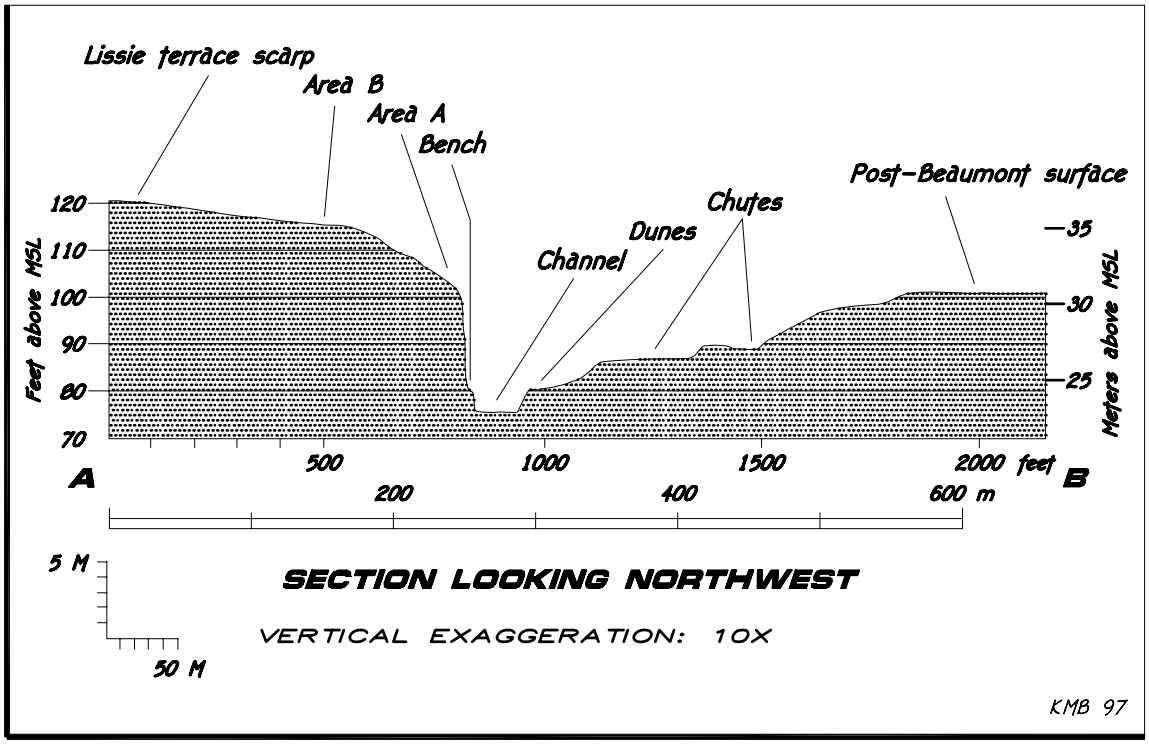


Figure 1.33. Cross-Section of Deposits Along Line A-B. This view looks upstream. Vertical exaggeration is 10X. Berger Bluff comprises Area A, Area B, and bench (base for topography: URS/Forrest and Cotton, Coleto Creek project map, sheet 140).

The cutbank along most of this reach of the creek just forms a vertical bluff with a low toe slope and a narrow, vegetated bank at its foot. At Berger Bluff, however, erosion of the overlying unconsolidated sediments has left a more resistant stratum remaining as a narrow erosional bench, the surface of which is about 1.5 m above the creek bed. The slumped and eroded area forms a shallow alcove (Fig. 1.34) about 7.5 m wide and approximately 22 m long. Much of this area is covered by slumped bluff deposits which form a steep toe slope 2.5 m high, extending to within four meters of the terrace surface. About 66 m^2 of the bench deposits remained clear of slumped fill at the beginning of

excavations. The toe slope was covered with leaf litter, grasses, a thick stand of ragweed, and a tangle of anaqua trees that had fallen from the bluff, mixed with some driftwood from floods in previous years. All of this loose vegetation was cleared off before excavation was begun.

Figure 1.34. Looking Southwest at Bench Area Before Excavation. Debris on bluff face and slipoff slope was removed at beginning of project. Note thick, well-developed soil at top of section, and excavated hearth (Feature 5, white area on shelf at right side). Photo taken November, 1979.

Plants growing on the toe slope included several grasses, such as hairy grama (*Bouteloua hisuta*), rabbitfoot grass (*Polypogon monspeliensis*), coast cockspur (*Echinochloa walteri*), savanna panicum (*Panicum gymnocarpon*), southwestern bristlegrass (*Setaria scheelei*), and vaseygrass (*Paspalum urvillei*), along with snow-on-the-prairie (*Euphorbia bicolor*), broomweed *(Xanthocephalum dracunculoides*), giant

ragweed (*Ambrosia trifida*), another unidentified composite, an unidentified legume, giant pokeweed (*Phytolacca americana*), dewberry (*Rubus trivialis*), and groundcherry (*Physalis* sp.). Some plant parts, generally leaves or wood, occurred as stream drift lodged on the slope, or as debris from the anaqua grove on the bluff. These included leaves and fruit of sycamore (*Plantanus occidentalis*), ash (*Fraxinus* cf. *pennsylvanica*) leaflets, bald cypress (*Taxodium distichum*) needles and wood, hackberry (*Celtis laevigata*) leaves, leaves of walnut or pecan (Juglandaceae), and possibly chinkapin oak (? *Quercus muehlenbergii*; plant identifications by Billy Griffin and Russell Castro, SCS; O. W. Van Auken, UTSA; and the author).

Very little is known about the spatial extent of cultural deposits near the base of the bluff. The distribution of more recent cultural debris on the surface of the blufftop is shown in the Flume No. 3 report (Brown 1986:Fig. 2), but the horizontal extent of the much older and more deeply buried archeological remains near the base of the bluff is likely to be somewhat different. A few isolated items were noted in the cutbank downstream from the bench area. Measured from the east end of the cutbank profile (at the 17-meter mark), these include some mussel shell and charcoal 20.1 m downstream; more mussel shell 23.3 m downstream; and charcoal and fired clay (?) 28.4 m downstream. All of these occurrences appear to be discontinuous, isolated items and are not considered part of the bench deposits. In two interviews (2/12/83 and 6/19/98) Bill Birmingham has passed along his recollections of the bench area when he visited the site in the 1960s. At the time, according to Birmingham, the cutbank lay farther to the north and the mussel shell zone in stratum 2A was denser and better defined, and included some chipping debris. he also recalls seeing a well-defined hearth near the top of the bench area. This hearth, evidently separate from and downstream from Feature 5, but

about the same size, had orange fired clay and was lined with hard objects (sandstone or fired clay).

The sandy creek bed is wide (25 m across at the bench), flat and shallow. The clear, steadily flowing water is in most places 20 cm deep or less. Several informants noted that in past years a large hole existed here, deep enough for fishing or swimming (Nelson Pantel, Stan Pantel, Leslie Berger, personal communication); it has since filled with sand, perhaps during Hurricane Beulah in 1967. They also remembered that in years past the main channel lay farther to the northeast; in fact, the channel split around a sandbar, the main part passing to the north, in an area now choked with sand. Both banks of the creek are lined with a narrow band of horsetails (*Equisetum* cf. *E. laevigatum*) and sedges (probably *Cyperus erythrorhizos* or *C. odoratus*).

Wide, flat, unvegetated sandbars, rhombohedral in plan view (Fig. 1.35), break up the channel, but shift position after each high discharge. On the opposite side of the creek is a vegetated lee side dune about a meter high, composed of clean, loose sand partially anchored by sedges and weeds (Figs. 1.36, 1.37). It isn't clear whether this deposit of windblown sand is derived from the active channel, delivered by the prevailing southeast wind, or from dry, loose sand in the chute to the northeast, driven by the north winds associated with Arctic frontal systems in late fall, winter, and early spring. The first possibility seems unlikely since most of the sand in the active channel is continuously damp and therefore not easily picked up even by strong winds. Determining the source of this channel-margin dune would help to clarify whether any of the deposits in the post-Beaumont terrace topstratum are eolian.

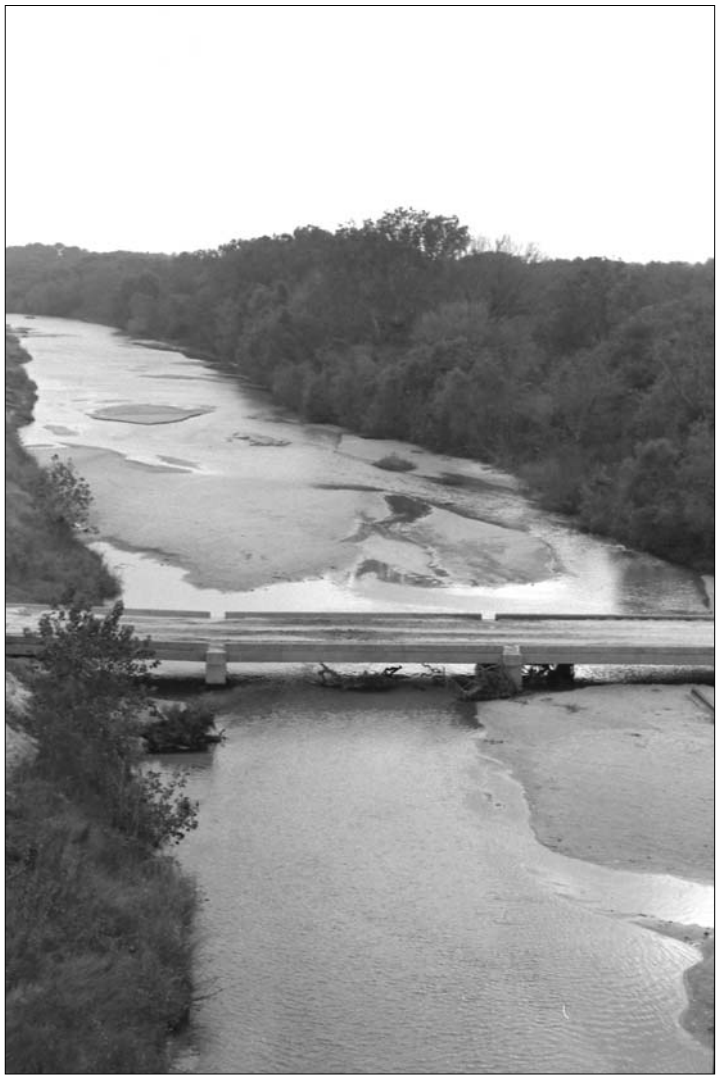


Figure 1.35. Coleto Creek Before Inundation. Looking upstream (northeast) at old Coletoville Road crossing of Coleto Creek. Note shallowness of modern channel and rhombohedral sandbars. Goliad County is to left, Victoria County to right.

Figure 1.36. Sand Dunes Opposite the Site. Looking north at small dunes bordering Coleto Creek northeast of site.

This long, narrow stabilized dune forms a continuous border between the active channel and a broad, flat overflow chute to the northeast. The chute (Fig. 1.37) is about 120 m wide, extending about 700 m both up and downstream from Berger Bluff. Its flat bottom is about three meters above the active creek bed and is interrupted by brush piles, small dunes and scours, and lag deposits of gravel and cobbles, possibly brought in by the record high discharge of Hurricane Beulah in 1967. A *chute bar* at the downstream end has formed where velocity of the overflow, reentering the main channel, decreases to such an extent that the sediment load can no longer remain entrained; most of the chute

opposite Berger Bluff is bounded by a low, sandy cutbank, beyond which a gentle slope slowly rises once more to the level of the post-Beaumont terrace surface.

Figure 1.37. Overflow Chute. Looking northwest (upstream) at overflow chute northeast of site, with ripples probably left by last flood event.

The lower reaches of Coleto Creek (chiefly in the Schroeder quad) are fairly well incised and really have no active floodplain except near its distal end, just before disemboguement onto the Guadalupe River floodplain. Here and elsewhere along its course, overflow chutes fill the function of an active floodplain by straightening and widening the channel during high discharge. During the flood of January 20, 1980, for example, flood stage at Berger Bluff peaked at about 83 feet MSL yet did not climb out of the chute opposite the site.

Several flow gauging stations are maintained on Coleto Creek and its tributaries, but the period of record for some of these is limited. One station (08176600), located on Threemile Coleto Creek near Cuero, is a partial-record station operated from 1969 to 1974. Another (8177000), at the Highway 622 crossing five kilometers upstream from Berger Bluff, was operated from January, 1930 to December, 1933, and from October, 1952 to November, 1979. It is the most useful data source for examining the hydrology of the Berger Bluff catchment up to April, 1980, when reservoir impoundment began to affect the stations downstream. It also corresponds to sampling locality "C-1" in the pre-inundation aquatic ecology study (Murray, Jinnette, and Moseley 1976). After March 6, 1980, the makeup pipeline diverting water from the Guadalupe River (southwest of Nursery) into the reservoir above the Highway 622 bridge became operational. Before this station was discontinued, another gauging station (0817900) was established 5.7 river kilometers upstream at the Arnold Road crossing of the creek, where the makeup pipeline cannot affect it, and this station has been in operation from October, 1978 to the present.

A station (08176550) is located at the US 183 bridge over Fifteenmile Creek about halfway between Weser and Upper Meyersville, but has daily mean discharge records only from October, 1984 to September, 1989, long after field work at Berger Bluff was completed. Another station (8177500) is located downstream from the site, near the Highway 59 crossing, and was operated from June, 1939 to September, 1954. A new series of stations (8176900 through 8177410) has been established in the reservoir area, but these are quite recent. The following discussion is based on the USGS records obtained from the stations mentioned above (data downloaded from the USGS web site), on observations of the creek itself, and on summary comments by Morton and Donaldson (1978) and the Coleto Creek Power Station EIS (Environmental Protection Agency n.d.).

THE CONTEMPORARY COLETO CREEK FLUVIAL SYSTEM

The drainage network for the catchment begins on the Gulfward-sloping face of the Oakville cuesta, near the Karnes-DeWitt county line, and passes through the former prairie occupying the Oakville Formation and Fleming Formation. The small creeks here (such as Salt and Little Salt Creek) are intermittent drainages that usually have no standing water except where scour pools are deep enough to intercept the water table; these are characterized by stagnant, turbid water. The streams are not incised much below the surrounding terrain, and there is no well-defined floodplain (Fig. 1.38). Streamcourses are often marked by gallery thickets of huisache, with willows at scour pools.

Farther down the catchment, south to east of Yorktown and still on the Fleming Formation, perennially standing or flowing water becomes more common, creek channels (such as Cottonwood or Smith Creek) generally have bimodally sized bed sediments, with mud and/or pebble or small cobbles on the bottom, and a weakly defined floodplain may or may not be present (Fig. 1.39). The Fleming Formation has a higher percentage of clay and other fine-grained sediments than the Oakville or Goliad Formation. The active channel may be anywhere from about a meter wide to about nine meters wide (where pools have formed behind obstructions). Willows are common along elongate pools.

Figure 1.38. Salt Creek. Looking east-southeast at scour pool in bed of Salt Creek, on Oakville cuesta near Old Davy, DeWitt County.

Figure 1.39. Smith Creek. Looking downstream at Smith Creek about four kilometers south of Yorktown, DeWitt County. Banks are clay-rich alluvium inset into Fleming Formation bedrock. Channel is about a meter wide, with mud and pebble bottom.

Where the drainage network crosses onto the Goliad Formation, to the west of US 183, the relief increases, the streams become more deeply incised, and they begin to carry the heavy sand bedload that is characteristic of the Coleto Creek drainage for the remainder of its course toward the Guadalupe River (Fig. 1.40). The increased relief is perhaps due to greater induration and, at least in the reach upstream from Berger Bluff,

due to the fact that this part of the outcrop has been probably been elevated as an upthrust fault block. Meandering channels (bordered by sedges and large willows) carrying a constant base flow of clear water between rhombohedral sandbars become common at this point. Twelvemile and Fifteenmile Coleto Creek, the two principal tributaries, are examples. Below their junction, the drainage is simply referred to as "Coleto Creek," and it is deeply incised into the surrounding terrain from this point until it passes onto the Lissie Formation. At the Arnold Road crossing, for example, the maximum depth of incision is about 14 m. The following discussion applies mainly to this lower section of Coleto Creek, from the Twelvemile-Fifteenmile Creek junction downstream to Berger Bluff.

The essential characteristic of Coleto Creek is its "flashy" discharge: long periods of low flow (or sometimes none at all) are broken by episodes during which the creek swells overnight to flood stage, then falls nearly as rapidly. These episodes generally last four days or less. Discharge usually peaks within 24 hours and returns to normal flow within the succeeding 72 hours, more or less. Sometimes a much smaller peak precedes or follows the main peak.

Figure 1.40. Coleto Creek. Looking upstream (west) at Eighteenmile Coleto Creek one kilometer south of Ander, Goliad County. Note small flowing channel incised into rhombohedral sandbars, and wide, flat floodway.

The significance of this discharge pattern is that very high velocities are periodically available to move larger caliber bedload material, but the sustained periods of turbulence necessary to move a substantial suspended load are absent, so the Coleto runs clear again soon after every flood. It is thus a *bedload stream* (Morton and McGowen 1980:39), rather than *a suspended load stream*, in Schumm's (1977:Table 5-4) terminology. Morton and Donaldson 91978:10350 classify the lower reaches as a *mixed-load* stream, but that does not appear valid for the rest of the drainage. These very high velocities are important since the weight of the largest particles of sediment entrained by the stream is proportional to the sixth power of the velocity (Mackin 1972:136). In other words, very large increases in velocity are necessary to effect relatively small increases in

competence (the ability of a stream to transport material of a certain caliber). This pattern contrasts with that of the Guadalupe River and San Antonio River, which transport chiefly suspended rather than bed sediments (Holley 1992:100).

Some idealized hydrographs are shown schematically in Figure 1.41. The lower part typifies contemporary Coleto Creek. The upper part illustrates another catchment (Black Cypress Bayou, upstream from Jefferson in Marion County) that is very nearly the same size but located in a wetter climatic regime, to show what the hydrograph of a suspended load stream might look like (it is also perhaps a good analog for Coleto Creek during the Pleistocene). The important thing to note here is that for fine-grained sediments (clay and silt) to be deposited on a floodplain or in a channel, the waning phase (recession limb) of a flood ought to persist for at least several days to allow very fine sediments to drop out of suspension. For significant accretion of fine-grained sediments on floodplains, persistence of stilling waters at overbank levels is required. Conditions like these are lacking in the modern Coleto Creek system, but are perhaps more likely in the Black Cypress Bayou drainage (I have no data on overbank flooding, however).

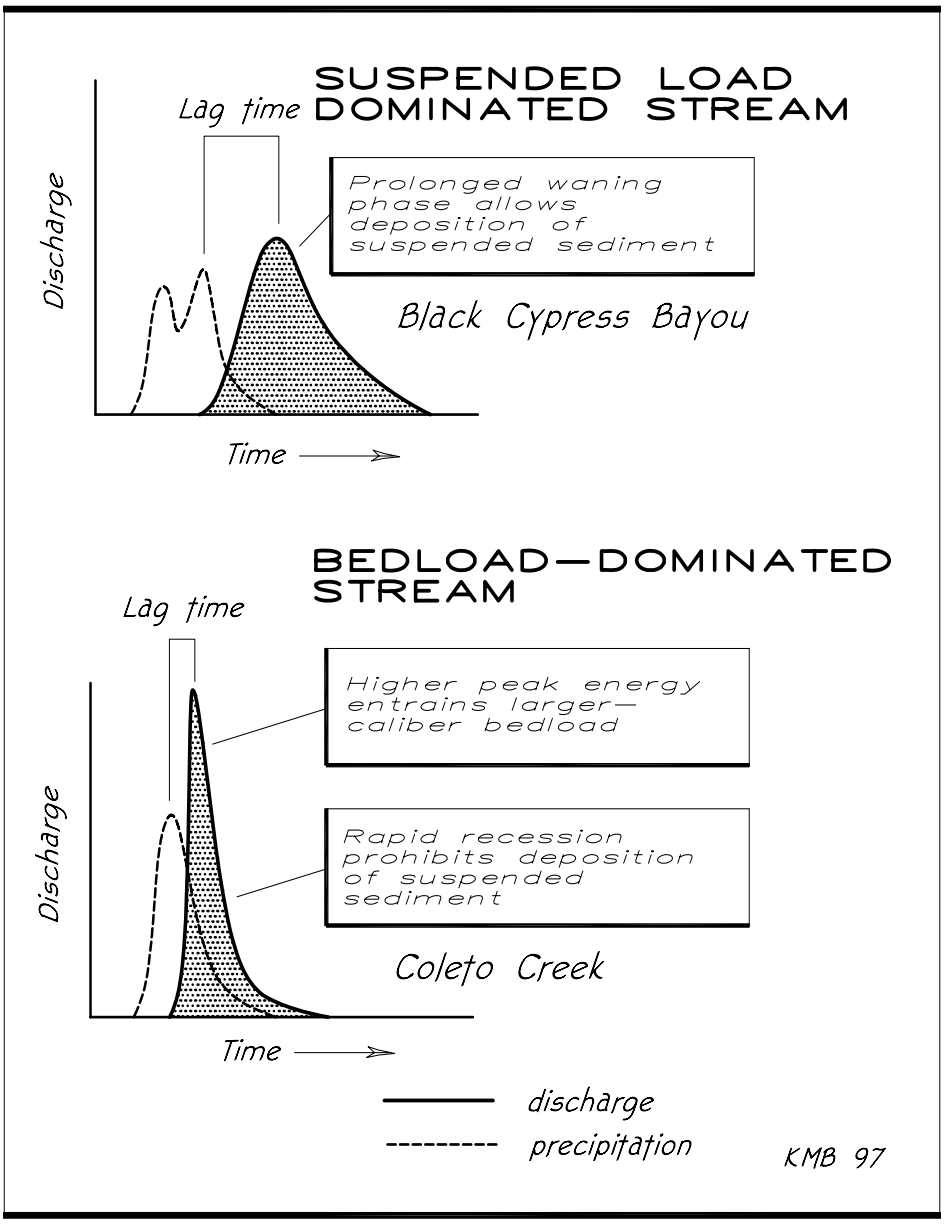


Figure 1.41. Idealized Hydrographs for Streams in Two Different Climatic Regimes. *Top diagram*, contemporary Black Cypress Bayou (Marion County) has a flattened hydrograph with slowly receding floodwaters that deposit suspended sediment, but cannot move a very heavy bedload. Pleistocene Coleto Creek might have looked much like this. *Bottom diagram*, contemporary Coleto Creek has flashy discharge, a very peaked hydrograph, and very little lag time between rainfall and flood events; it can move a very heavy bedload but cannot deposit much suspended sediment.

Rainfall and runoff

In order to illustrate some of the pre-inundation characteristics of Coleto Creek, I have prepared hydrographs and rainfall graphs for five different years. In each of these diagrams, discharge at USGS station 08177000 (the Highway 622 bridge over Coleto Creek, five kilometers upstream from Berger Bluff) is plotted in cubic feet per second (left vertical axis), while rainfall at Yorktown is shown in inches (right vertical axis). For heuristic purposes, I have selected two ENSO cold event years (1956 and 1975), two ENSO warm event years (1957 and 1976), and the year 1967 (another ENSO cold event year) is shown to illustrate the effects of Hurricane Beulah. Hurricane Beulah broke the drought of 1960-67, which was nearly as severe as that of 1950-57. The first figure (Fig. 1.42) shows the transition between 1956, the worst drought year of the 1950s, and 1957, a rainy year that broke the drought. The figure showing 1975-76 (Fig. 1.43) shows the period just before excavations at Berger Bluff, the same two years during which the aquatic ecology of the creek was studied by Murray, Jinnette, and Moseley (1976). These five years should give a good picture of how contemporary climate shapes the hydrologic character of the creek.

The discharge peaks shown on the graphs are perhaps best termed "discharge events" or "streamflow peaks," rather than "flood events," since presumably only the largest events shown here exceed the bankfull capacity of the creek. I have not tried to identify which events represent actual overbank floods. Several things can be noted by studying the Coleto Creek hydrographs:

Figure 1.42 *(following page)*. Coleto Creek Hydrographs for 1956 and 1957. Rainfall at Yorktown and flood events (gauged at Highway 622 bridge near Schroeder, USGS station 08177000) plotted on the same timeline to show lag time (for example, the upper diagram runs from January 1956 on the left to January 1957 on the right). Note short duration and peakedness of flood events, and clustering in May and November. Precipitation in inches (scale on right vertical axis), discharge in cubic feet per second).

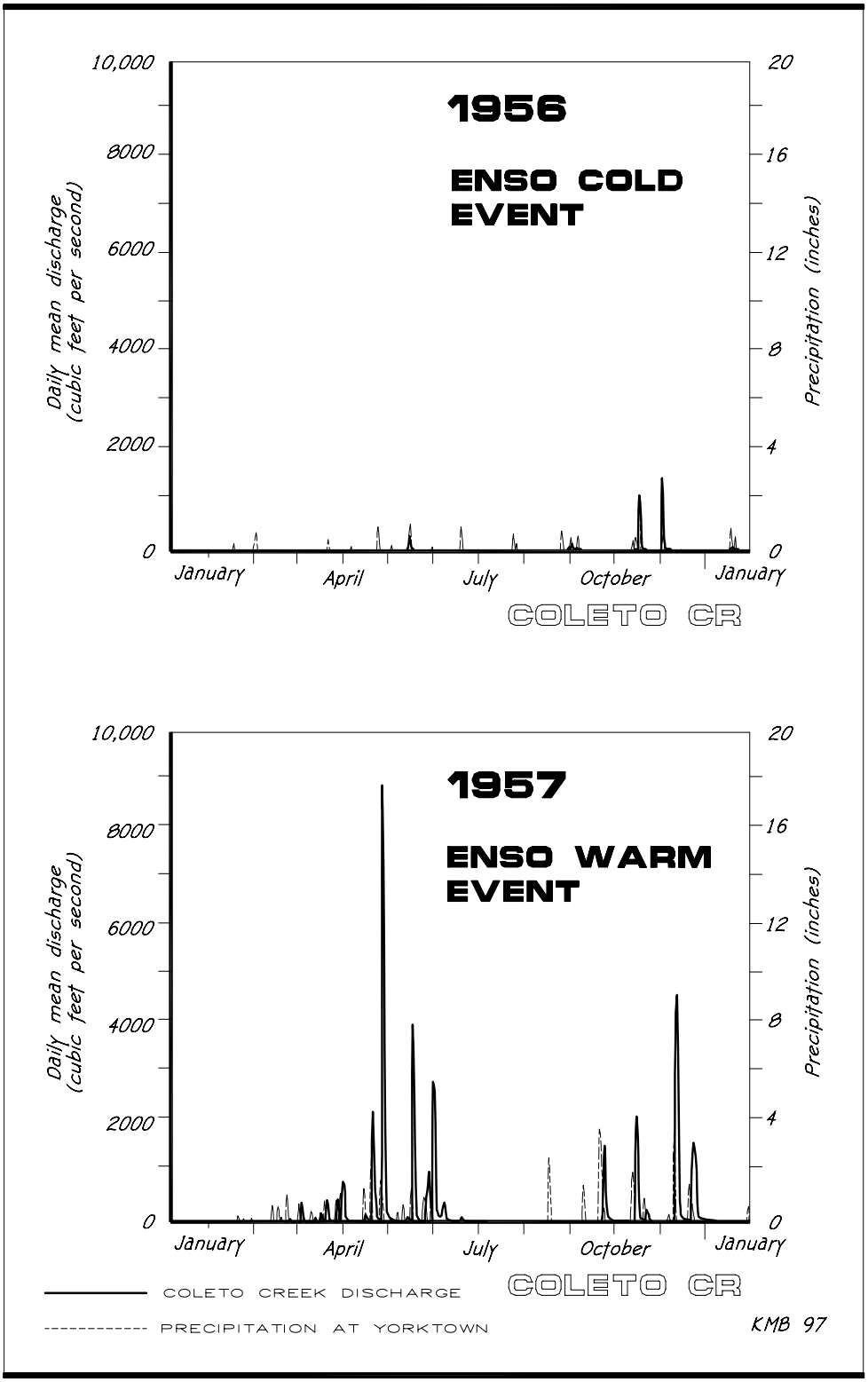
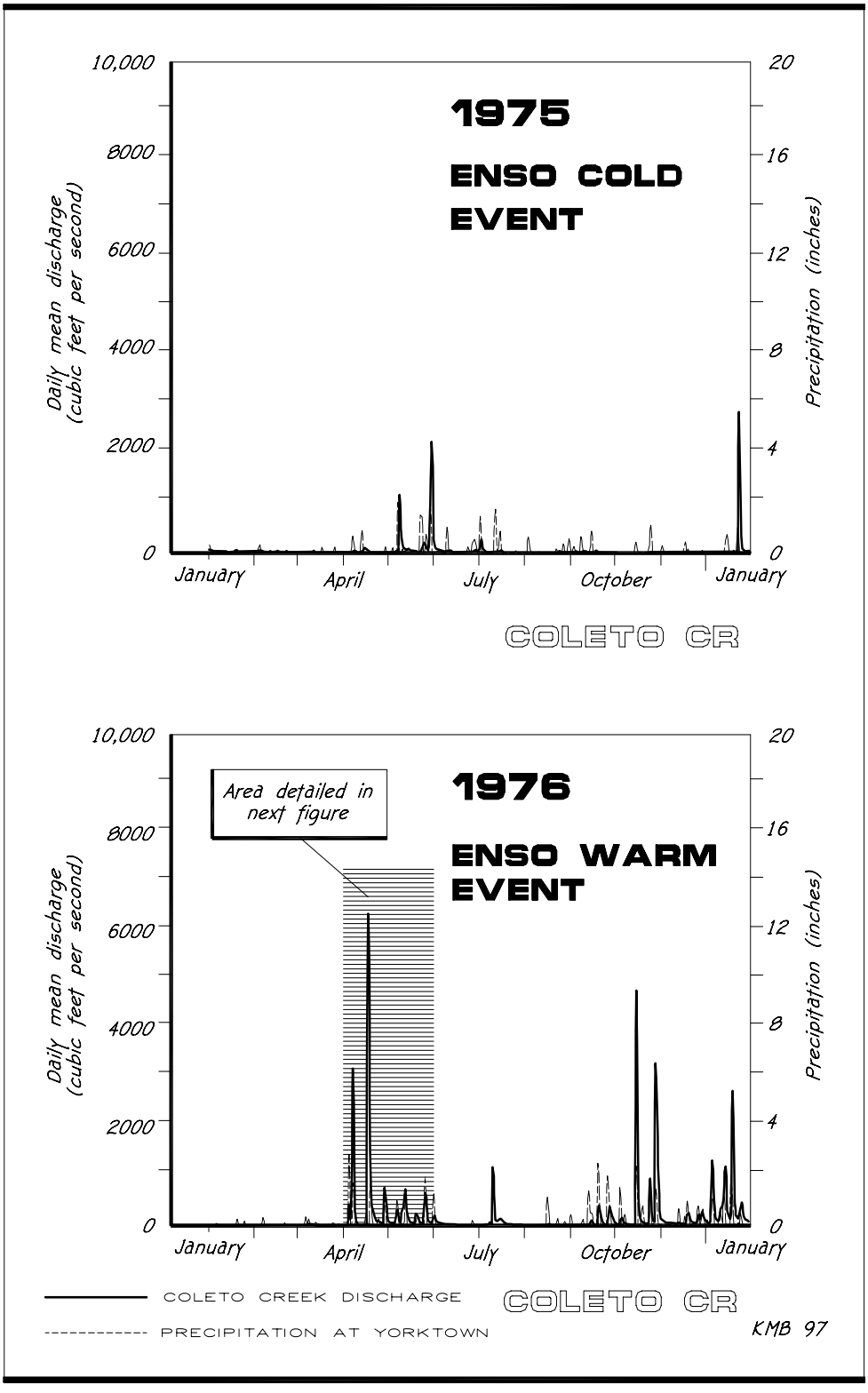

1956
ENSO COLD EVENT
10,000
8000
6000
4000
2000
0
20
16
12
8
4
0
Daily mean discharge (cubic feet per second)
Precipitation (inches)
January
April
July
October
January
COLETO CR
1957
ENSO WARM EVENT
COLETO CREEK DISCHARGE
PRECIPITATION AT YORKTOWN
KMB 97

Figure 1.43 *(following page)*. Coleto Creek Hydrographs for 1975 and 1976. Rainfall at Yorktown and flood events (gauged at the Highway 622 bridge near Schroeder, USGS station 08177000) are plotted on the same timeline to show lag time.


1975
ENSO COLD EVENT
Daily mean discharge (cubic feet per second)
Precipitation (inches)
10,000
8000
6000
4000
2000
0
20
16
12
8
4
0
January
April
July
October
January
COLETO CR
1976
ENSO WARM EVENT
Area detailed in next figure
COLETO CREEK DISCHARGE
PRECIPITATION AT YORKTOWN
KMB 97

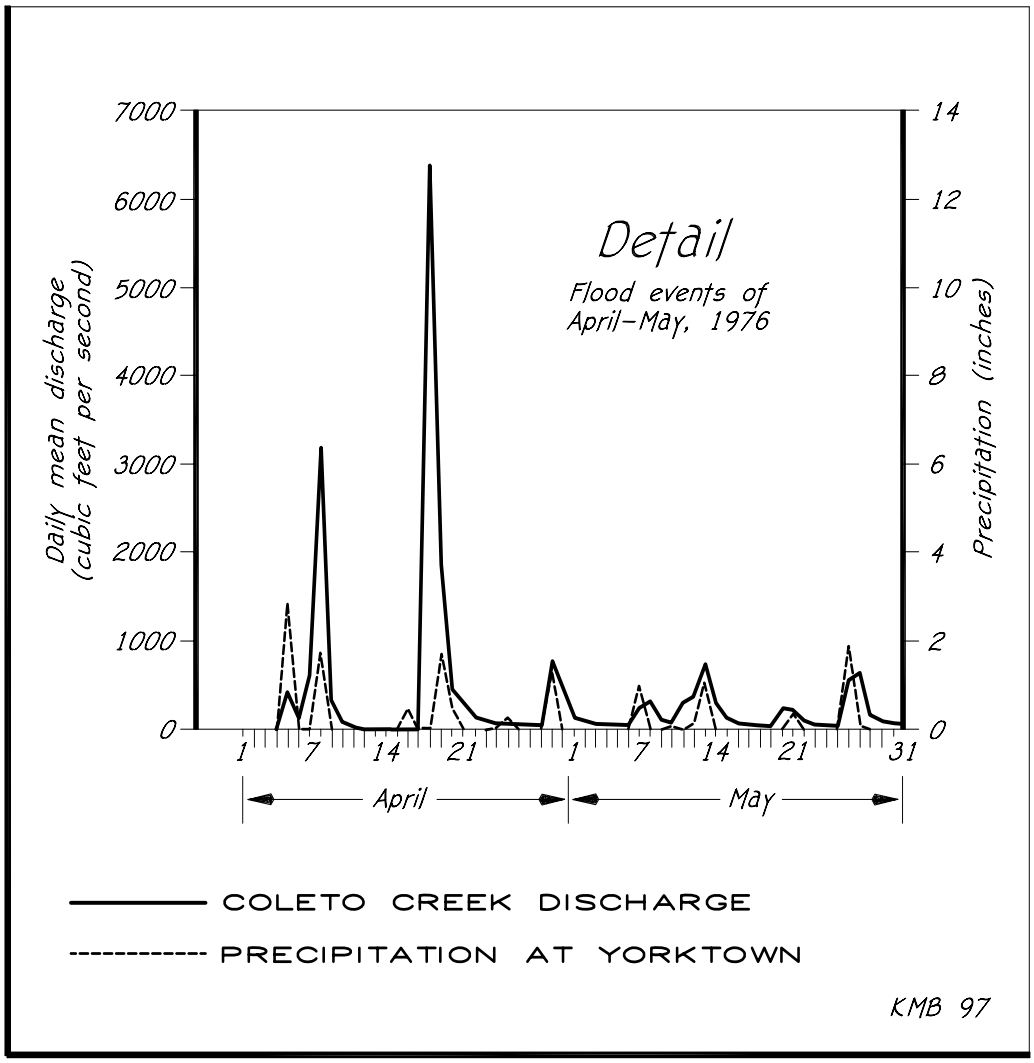


Figure 1.44. Detail of Coleto Creek Flood Events, April-May, 1976. The hatched area in the previous figure is shown here in greater detail. Each tick mark on the X axis represents a day's time. Note that most flood events gauged at the Highway 622 bridge are either simultaneous with or at most, follow by one day the corresponding rainfall event measured at Yorktown.

1. Rainfall and runoff events are clustered, usually in April-May, October, and sometimes January.

2. Base flow for Coleto Creek is so low that it is not visible on these graphs.

3. Discharge events at Highway 622 follow rainfall events so closely that on these illustrations, the rainfall peaks are usually hidden behind the discharge peaks. In Figure 1.44, I have shown an enlarged detail of the months of April and May from the preceding figure so the time relationship can be seen better.

4. As the detailed illustration shows, discharge events often occur on the same day as a rainfall, or sometimes on the following day. The discharge event of April 18, 1976, actually *precedes* by one day the main rainfall event of 1.7 inches at Yorktown.

5. Study of the numerical data shows that there are many small rainfall events that do not show up in the discharge curves. Usually these are in late summer, when the ground is dry and rainfall is directly absorbed without running off. There are also some discharge events with no corresponding rainfall at Yorktown. This suggests the drainage basin is sufficiently large that a single central station like Yorktown is not adequate to capture all rainfall events.

6. The recession limb for Coleto Creek discharge events is rarely more than about three or four days.

In Table 1.8, I have tried to estimate average lag times between rainfall events and clearly related discharge events. Sometimes this is difficult, when a series of rainfall and discharge events overlap (especially in the case of Black Cypress Bayou). As the table shows, average lag time is only about half a day, indicating that rainfall at Yorktown moves as runoff into the lower Coleto Creek drainage very rapidly (overland distance between these two recording stations is about 35 km). I have not tried to compute mean length of the discharge recession limb, but it clearly would not be much longer.

Table 1.8. Mean Lag Time for Discharge Events, Coleto Creek and Black Cypress Bayou.

Year	**Mean lag time (days)**	**Standard deviation (days)**	**Number of discharge events examined**
Coleto Creek at Highway 622 Bridge			
1956	0.409	0.309	11
1957	0.625	0.567	20
1967	0.423	0.549	13
1975	0.556	0.762	18
1976	0.548	0.615	21
All 5 years	0.530	0.627	83
Black Cypress Bayou at Jefferson (Marion County)			
1975	3.14	1.125	7
1976	2.75	2.046	12
Both years	2.89	1.77	19

Figure 1.45 shows the largest discharge on record at the Highway 622 gauging station. On September 21, 1967, 10.62 inches of rain fell at Yorktown during Hurricane Beulah (followed by 9.49 inches the next day), and a peak average daily discharge of 74,800 cfs was recorded at the station. After the flood, the maximum instantaneous discharge was computed at 122,000 cfs based on a flood stage of over ten meters (from the evidence of flood marks). The discharge averaged over the entire day is shown in Figure 1.45; for a hydrograph of the instantaneous value, see Schroeder *et al*. (1974:Fig. 24) and Morton and McGowen (1980:Fig. 23). According to local residents, this represents the highest stage since at least 1872 (USGS 1974:85), indicating that flood may be close to the "hundred-year flood" for Coleto Creek (the peak discharge for the Guadalupe River on the same day was actually slightly smaller, 70,000 cfs; US Army Corps of Engineers 1968:Table 5). Note that because this flood was nearly an order of magnitude larger than previous ones, both vertical scales on the figure have been changed compared to the other figures. Other major flood events occurred at the Highway 622 station in 1946 (63,700 cfs) and 1925 (46,700 cfs).

Convective thunderstorms cannot produce rainfall over an entire basin the size of the Berger Bluff catchment. Thunderstorms associated with a frontal passage can cover a larger area, but a hurricane, even if it merely approaches the catchment without entering it, can cover the entire basin with simultaneous rainfall, and can produce two or three days of continuous rain, as Hurricane Beulah did.). Pettus, in Bee County, received over 27 inches of rain over the course of several days. The hurricane struck the coast near Brownsville on September 20, traveled northwest to Duval County, then on the following morning stalled and veered southwestward into Mexico. At the turn point in Duval

County on the 21st, the center track of the hurricane remained 190 km away from Yorktown (Schroeder *et al*. 1974:Plate 1), yet still produced record-breaking rainfall. On September 21, 10.0 inches of rain fell eight miles west of Nursery, 16.0 inches at Fannin, and 18.0 inches at Victoria; on the 22nd, 21.02 inches fell at Weesatche, while 22.2 inches fell 10 miles northwest of Victoria, and at least 21.0 inches fell eight miles southeast of Yorktown (Schroeder *et al*. 1974:Table 2. Despite the magnitude of this flood, flow had returned to less than 100 cfs by October 1.

Although frontal passages can also cause severe flooding and erosion, there are some significant differences in scale that might be recognizable in the geological record. Frontal passages tend to be fast-moving, often producing no more than a couple of days of rainfall, and they generally move north to south in this region, or down-drainage. Large hurricanes can be immense. Some of the more recent examples have been observed to cover nearly the entire Gulf in satellite imagery. A storm of this size can easily cover most of the eastern half of Texas, even after moving inland, and the sprawling circulations of such storms tend to produce a lot of rain. A large hurricane can change track and meander around the state for over a week, as Hurricane Amelia did in 1978. Hurricanes also tend to move east to west or southeast to northwest, and up-drainage in relation to the major river systems. Systems like this are potentially capable of more severe and prolonged flooding than convective thunderstorms. Largely because of ENSO influence, hurricanes tend to be clustered in time, which might mean that their geologic signatures could also be clustered in time.

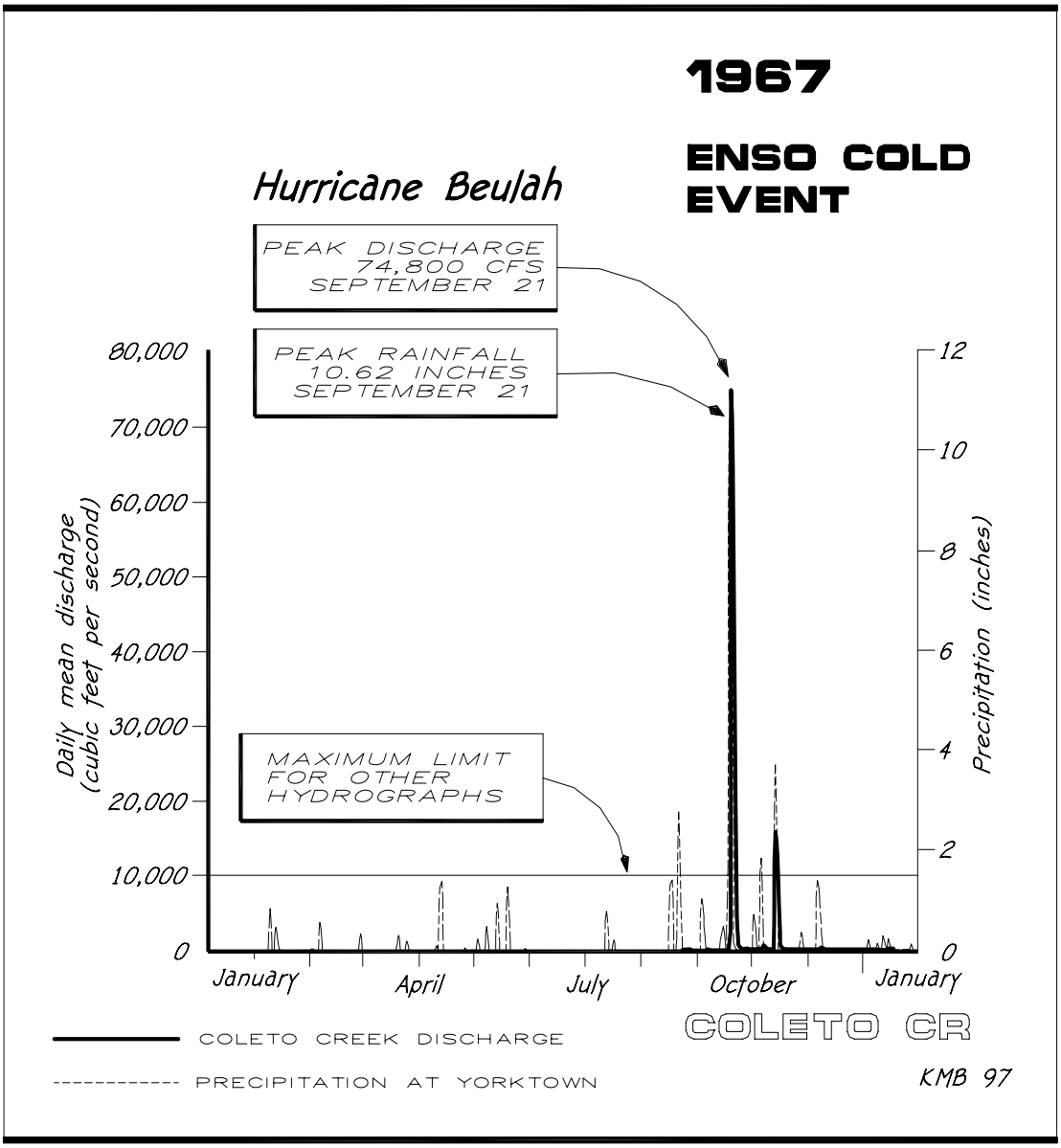


Figure 1.45. Coleto Creek Hydrograph for 1967, Showing Effects of Hurricane Beulah. Because of the record discharge for this year, both vertical axes are scaled differently from the other hydrographs shown here. The horizontal line at 10,000 cfs is the maximum shown on all the other hydrographs. Note that the rainfall peak is concealed behind the flood peak.

Effects of flooding on biota

Both the present-day marginal vegetation and the aquatic fauna of the lower reaches of Coleto Creek are adapted to its flashy discharge. Sycamore *(Platanus occidentalis*), black willow (*Salix nigra*), and cottonwood (*Populus deltoides*) are the most important stream-margin species in this part of the drainage (Espey, Huston and Associates 1976:2-3). These are all water-loving species, but they are also fast-growing species well adapted to rapidly recolonizing sandbars after washouts. Telfair (1987:Table 1) classifies species like these as inundation Zone III indicators. These three species first flower at 25, 10, and 10 years of age, respectively, and have normal lifespans of 250-500, 50-125, and 60-100 years (Altman and Dittmer 1962:Table 103). Very large live *oaks (Quercus virginiana*) are also members of the bottomland forest, but grow on the well-drained upslope margin of the bottomland, probably well out of reach of the hundred-year flood zone. Most oaks first flower at about 20-35 years, and live oaks have a normal lifespan of 200-300 years (Altman and Dittmer 1962:Table 103). Live oaks are Zone V indicators (Telfair 1987:Table 1). There are also chinquapin oaks and a good many elms growing on the terrace scarp at the Arnold Road crossing of Coleto Creek. The distribution and composition of floodplain vegetation is rather similar to that reported for the San Antonio River near Floresville (Bush and Van Auken 1984). The small aquatic plants and animals in the creek tend to show wide seasonal variance in abundance and species diversity, changing with flow conditions and frequency of washouts. Among the benthic fauna, the only mollusks recovered in an aquatic ecology study done for Central Power and Light Company were the Asiatic clam (*Corbicula manilensis = Corbicula fluminea*), limpets (*Ferrissia* sp.) and aquatic snails (*Physa* or *Physella* sp.). Although 32 species of fish were recorded, most of these were smaller fish — minnows, mosquitofish,

crappie, sunfish, and the like. Larger species such as the yellow cat were recorded, but only as juveniles (Murray, Jinnette, and Moseley 1976). Over much of its length the Coleto is too shallow to support larger species of fish; occasional large pools as much as a couple of meters in depth occur, but these are frequently relocated by high discharge reworking of bed sediments. Perennial pools may support large populations of frogs.

Channel form and bed sediments

A fluvial system is an example of a natural system in dynamic equilibrium. The term "dynamic equilibrium" means that the system is stable at any one moment in time, but eventually one or more components of the system will change, after which all the other components readjust themselves, resulting in a new state of (temporary) equilibrium. System variables such as discharge, amount and grain size of sediment load, channel form, sinuosity, and gradient are all interrelated. Geologists tend to view sediment load and discharge as independent variables and the others as dependent variables. Lower Coleto Creek, adapted to carrying a heavy sand bedload with variable discharge, shows many features of *coarse-grained point bar* (McGowen and Garner 1975) and *braided stream* systems (although it has not actually developed multiple channels). The *channel width/depth ratio* is very high; at Berger Bluff, the channel width during normal flow is 24 m and depth averages around 20 cm; the ratio at bankfull discharge is unknown but would probably be similar. *Sinuosity* is very low; for a reach of Coleto Creek about 15 river kilometers in each direction from the site, it is 1.02. This figure is somewhat lower than that (1.37) reported by Morton and McGowen (1980:39), perhaps because they interpret the extent of the floodplain differently, or because the Coleto is more sinuous in their study area. *Channel gradient* over the same section at Berger Bluff is about 1.57 m/km. There is about 152 m of relief in the entire catchment.

Morton and McGowen (1980), in their study area farther downstream, recognize three major depositional features: alternate side-attached bars (Fig. 1.46), point bars with chutes, and point bars without chutes. Similar features are found at Berger Bluff and upstream in the catchment. The most prominent features of the creek at Berger Bluff are the long, arcuate chutes occupying the insides of bends. These help to carry excess water during periods of peak discharge, widening and straightening the channel; the thalweg is presumed to remain in the active channel, however, rather than migrating to the insides of bends. Since the floor of the chute is elevated above that of the active channel, the chute dries rapidly as flood stage falls, leaving extensive scour-and-fill features preserved. In the active channel, high flow regime structures are soon reworked during normal flow, but in the chutes, reworking is mainly confined to wind erosion and redeposition. Peak discharge is also recorded in the caliber of the bedload left in the chute: lag deposits of chert and petrified wood cobbles are exposed on the bank and in scours in the chute at Berger Bluff. These almost certainly were deposited in 1967 during Hurricane Beulah; discharge since then has been insufficient to remove them. Similar cobbles, up to about 12 cm (estimated) in maximum dimension can be seen in point bar deposits at various places in the catchment. Small gravel bars of similar caliber material can be seen in the active channel just downstream from the confluence of Twelvemile and Fifteenmile Coleto Creek (Fig. 1.47). The rate of movement of clastic particles through the catchment is probably inversely proportional to their caliber, with very large cobbles perhaps not moving at all except during floods with a recurrence interval of a century or so.

Figure 1.46. Coleto Creek. Looking upstream from a point about 300 m upstream from the bench area before reservoir inundation. Note side-attached bar.

Bedforms visible in the active channel at Berger Bluff are primarily small scale ripples, often with small (pea-sized) lag gravels in the pockets between the ripples. The flood of January 20, 1980 gathered these gravels and rearranged them as long stringers armoring the planar bed along the thalweg, but was unable to loft the pebbles out of the channel. Two sediment samples from the bed of Coleto Creek were collected for grain size analysis during field work in the spring of 1980. Both were collected soon after the January 20 flood. Sample #1 was collected in the thalweg just upstream from a midchannel bar opposite the bench at Berger Bluff. Sample #2 came from slightly farther upstream and includes the layer of lineated gravels mentioned above; some of the sand immediately below the gravel is also included. The ratio of sand to gravel is therefore strictly a function of the thickness of the sample collected; both represent only the upper

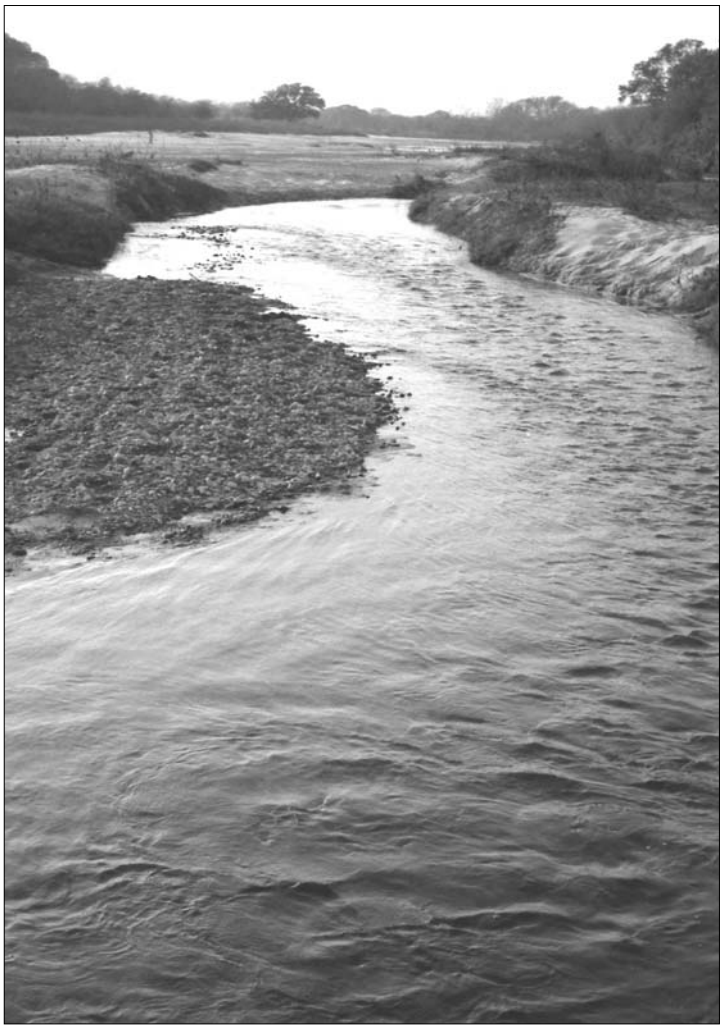


Figure 1.47. Coleto Creek. Looking upstream near Arnold (Camp Colet) Road crossing; photo taken in February, 1983. Creek has moderate sinuousity and small gravel bars here. Channel is floored with chert cobbles at this riffle, possibly left by Hurricane Beulah flooding.

4 or 5 cm of sediment. Sample #2 contained juvenile Asiatic clams (*Corbicula manilensis* = *Corbicula fluminea*). These are quite abundant in the creek bed at the site.

Bed sample #1 is composed chiefly of coarse and medium-grained sand and is bimodal, with modes at the 0.5 to 1.0 and 1.5 to 2.0 grades. Sample #2 is more variable;

the gravel population is unimodal, at -2.5 to -2.0 phi, and the sand population is also unimodal, at 1.0 to 1.5 phi (Fig. 1.48; the Wentworth grade scale, represented by phi, will be explained in the chapter on sedimentology). Both samples are significantly coarser than the early sediments from the bench area. Fines (sediment finer than 4.0 phi) were not analyzed, but amount to only a fraction of a percent in both cases.

A third sample was collected in April, 1983 from the bed of the Twelvemile Coleto southeast of Meyersville, 33.6 river kilometers upstream from Berger Bluff. It contains no gravel but is very well sorted, with a very pronounced peak at 1.5 to 2.0 phi. Nearly all the sample falls in the coarse to fine sand range.

Bedforms and channel morphology in the lowest reaches of Coleto Creek have been described as follows by Morton and Donaldson (1978:1034-1035):

> Major bed forms along the meandering channel of Coleto Creek are alternate bars and point bars. These bars, which are active only at high discharge, are incised and modified by a low-stage meandering thalweg within the channel. Point bars consist of lower and upper point-bar deposits separated by a scour trough or chute. Point-bar morphology is similar to that of coarse-grained point bars of the Amite and Colorado Rivers described by McGowen and Garner (1970), but grain size of Coleto Creek bars is substantially less. Lower and upper point bars of Coleto Creek are each about 3 m thick, giving a total bar thickness of about 6 m. These bars are submerged during moderate to high discharge, when sediment is transported across the entire bar surface. Bar surfaces exhibit low-relief rhomboid ripples and ripples on megaripples with sinuous lee faces extending transversely across the bar. Mud drapes occur as thin veneers over the bar and as local concentrations between small bed forms. Other high-discharge bed forms include flat-crested medial bars stabilized by vegetation. These bars have steep lee faces and are 1.8 to 2.1 m high.
>
> Bed forms in the low-stage thalweg are primarily transverse bars with amplitudes less than 1 m and wave lengths of about 30 m. Some of these transverse bars are marked by scour troughs that contain lag gravel and that form upstream from clumps of vegetation.

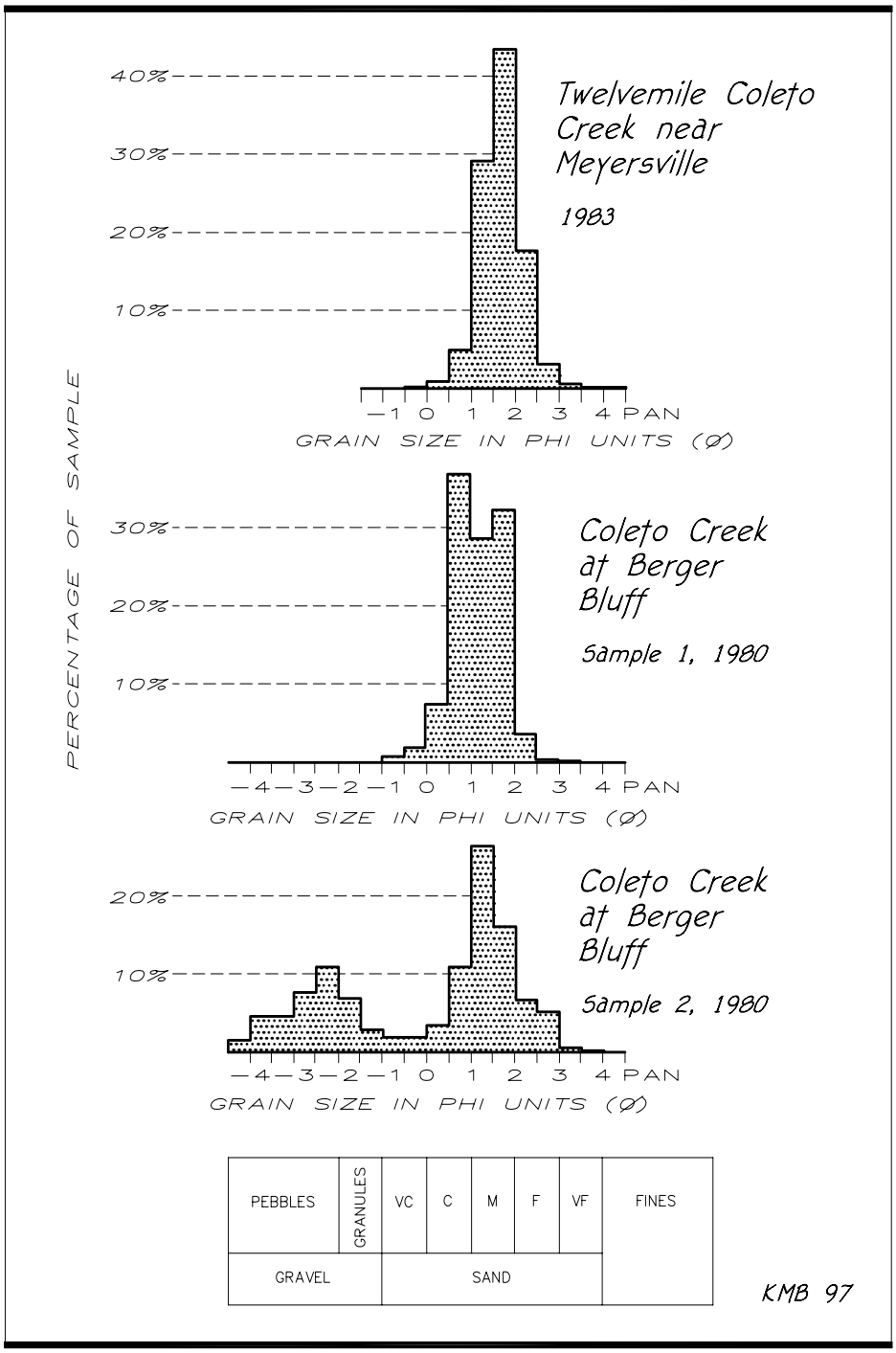


Figure 1.48. Grain-Size Histograms for Three Samples of Bed Sediment. Top, Twelvemile Coleto Creek, 1.9 km southeast of Meyersville; middle, creek bed opposite Berger Bluff; bottom, sample slightly farther upstream. Grain size in phi units.

From the discussion that has been presented so far it should be apparent that Coleto Creek is well adapted to the present climatic regime — one with fairly pronounced seasonal distribution of rainfall, and a tendency for relatively rapid concentration of runoff within the catchment. Channel form, for example, is adapted to rapid throughflow. The straightness of the channel promotes rapid discharge, and the slightly elevated high-water chutes serve to straighten further the channel and to provide additional capacity by greatly broadening it at flood stage. At very high discharge, the creek actually reexcavates the areas occupied by the bars, entraining the sediment and sending it downstream. Morton and McGowen speculate that the large-scale sedimentary structures visible in their trenches are relics of the 1967 flood. Shallow, flat-bottomed, wide channels, augmented mostly in width rather than depth by flooding are characteristic of drainages in areas with seasonally uneven precipitation (see Gupta 1975).

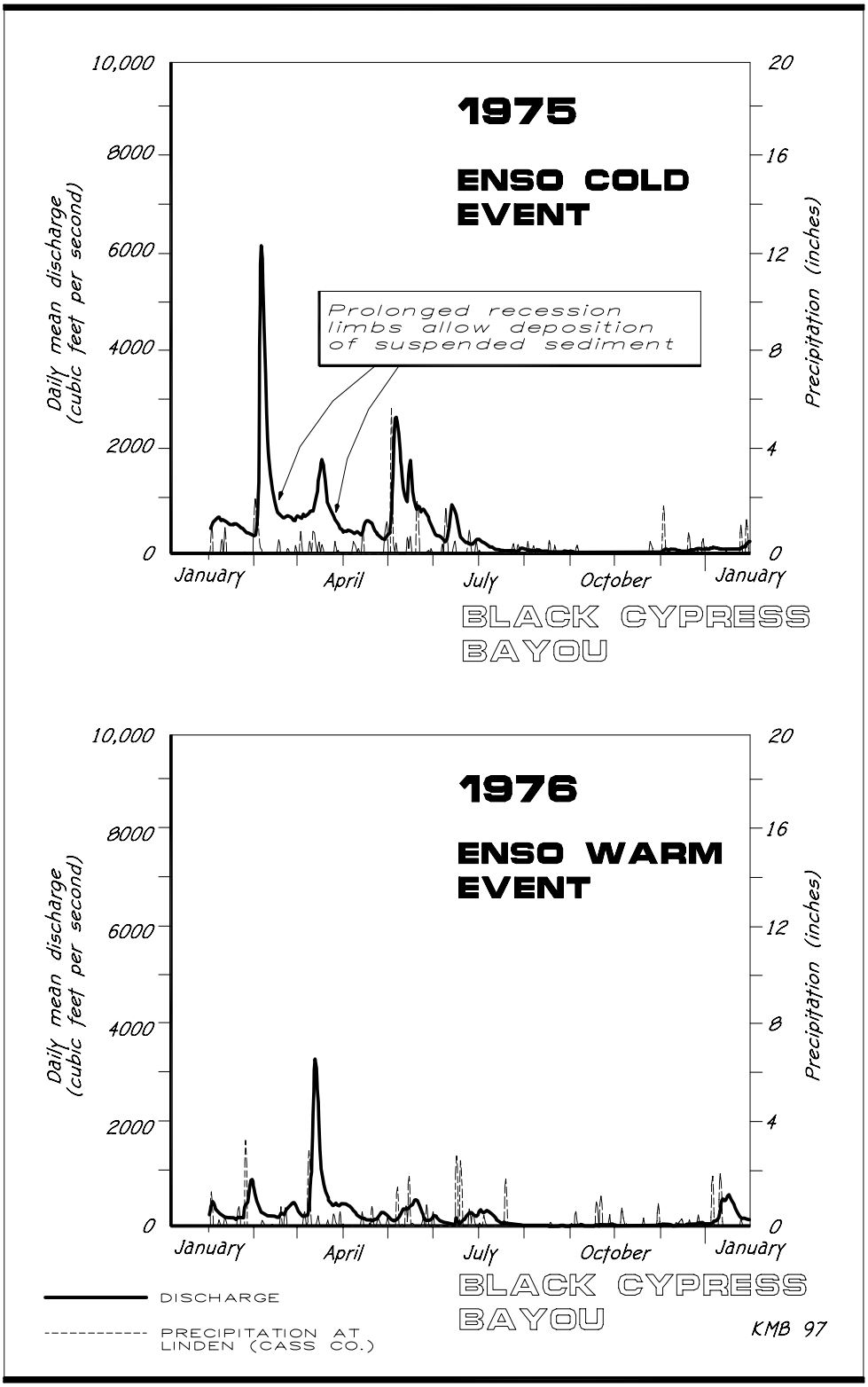
The frequency of the flows on the Coleto inhibits growth of vegetation on the bars, and in fact slow-growing species such as live oak (*Quercus virginiana*) are excluded from most of the flood zone, so there is very little vegetation to impede discharge.

Comparison with Black Cypress Bayou

In order to get some idea of what the discharge behavior of Coleto Creek might look like under a different climatic regime, I have compared it to Black Cypress Bayou. This catchment, gauged at Jefferson (Marion County) has an area of 945 km^2, nearly the same as the 956 km^2 area above the Highway 622 station on the Coleto. There is about

100 m of relief in the catchment, compared to 152 m in the Berger Bluff catchment. Most of the catchment lies in Cass County and Morris County. The precipitation values shown were gauged at Linden, which is spatially positioned in the Black Cypress catchment much as Yorktown is in the Berger Bluff catchment, except that it is offset to the east of the drainage. Black Cypress Bayou is shown as a heuristic example of a non-flashy stream, one with a much more even annual discharge, located in a wetter and more heavily vegetated part of the subtropical humid climatic zone (Larkin and Bomar 1983:2), with maximum rainfall in April and November-December (Natural Fibers Information Center 1987:90). Annual rainfall is about 117.5 cm (46.3 inches). Figure 1.49 shows rainfall and runoff for 1975 and 1976. As the illustration shows, rainfall events are small but frequent, base flow is relatively high from winter until early summer, and notably, the recession phase of discharge events is quite prolonged. In the flood event of February 3, 1975, for example, the stream takes about two weeks to return to base flow level. The average lag time between rainfall events and related discharge events is almost three days (Table 1.8), indicating movement of rainfall into the drainage system is relatively slow, presumably impeded by heavy vegetation cover (the overland distance from Linden to Jefferson is about 27 km). Figure 1.50 shows the probability of a given peak discharge for the two streams, based on historical discharge records. The curves were generated by PEAKFQ, a computer program produced by the United States Geological Survey (Slade and Asquith 1996). Coleto Creek (the upper curve) clearly has a higher probability of a given peak discharge and is a much "flashier" stream (although the periods of record are not the same). Note also that the maximum discharge shown is defined by the 1967 Hurricane Beulah flood.

Figure 1.49. *(following page)*. Hydrographs for 1975 and 1976, Black Cypress Bayou (Marion County). Rainfall at Linden (Cass County) and flood events (gauged at Jefferson, USGS station 07346045) are plotted on the same timeline to show lag time. The scale for rainfall is on the right vertical axis. These east Texas hydrographs are shown as an example of a similar-sized basin in a different climatic regime, one that might have resembled somewhat that found at Berger Bluff in the Pleistocene. Note the somewhat more frequent rainfall events, higher base flow level, more prolonged falling limb for each flood event, and relatively constant flow from winter through early summer. The bimodal May-September rainfall peaks seen in the Berger Bluff catchment are not visible here. Precipitation is in inches, discharge in cubic feet per second.


1975
ENSO COLD EVENT
Prolonged recession limbs allow deposition of suspended sediment
Daily mean discharge (cubic feet per second)
Precipitation (inches)
10,000
8000
6000
4000
2000
0
20
16
12
8
4
0
January
April
July
October
January
BLACK CYPRESS BAYOU
1976
ENSO WARM EVENT
Daily mean discharge (cubic feet per second)
Precipitation (inches)
BLACK CYPRESS BAYOU
DISCHARGE
PRECIPITATION AT LINDEN (CASS CO.)
KMB 97

Black Cypress Bayou corresponds — physically, hydrologically, and in climatic setting — more closely to how Late Pleistocene or early Holocene Coleto Creek might be envisioned. It is ideally suited for carrying large quantities of fine sediments since the minimum turbulence necessary to keep fine sediment in suspension is available for sustained periods. Movement of runoff through this catchment is clearly much more prolonged than in the Berger Bluff catchment. This could be a result of several different factors, such as somewhat lesser relief, perhaps coarser-grained soil cover, or a more convoluted and meandering drainage network in the Black Cypress Bayou catchment, but most likely the key factor is much heavier vegetation cover, intercepting and slowing the progress of rainfall into the drainage network. Another factor might be the possible tendency for rainfall events in this part of east Texas to be clustered in time. Small but closely repeated rainfall events serve to maintain base flow in the drainage.

ANTIQUITY OF THE MODERN HYDROLOGIC REGIME

Coleto Creek is presently incising its earlier deposits and in fact appears to have cut completely through the entire Holocene sequence of sediments. Nowhere in this stratigraphic sequence is there clear evidence of previous incisive events. Apparently the entire section represents uninterrupted aggradation, right up to the point when the present episode of downcutting began. This change in stream behavior, then, seems to indicate the reversal of a trend spanning several millennia and must as well indicate a major hydrologic change, or more likely the passing of some kind of hydrologic *threshold*. Dating this event is therefore a matter of some interest. The study of aquatic ecology done for Central Power and Light Company assumes the event is recent:

> Land clearing and alterations in native vegetation have reduced the retention capacity of the watershed, resulting in greater runoff and stream discharge.

Channel bottoms tend to be very unstable due to flash erosion and sediment loading (Murray, Jinnette, and Moseley 1976:1).

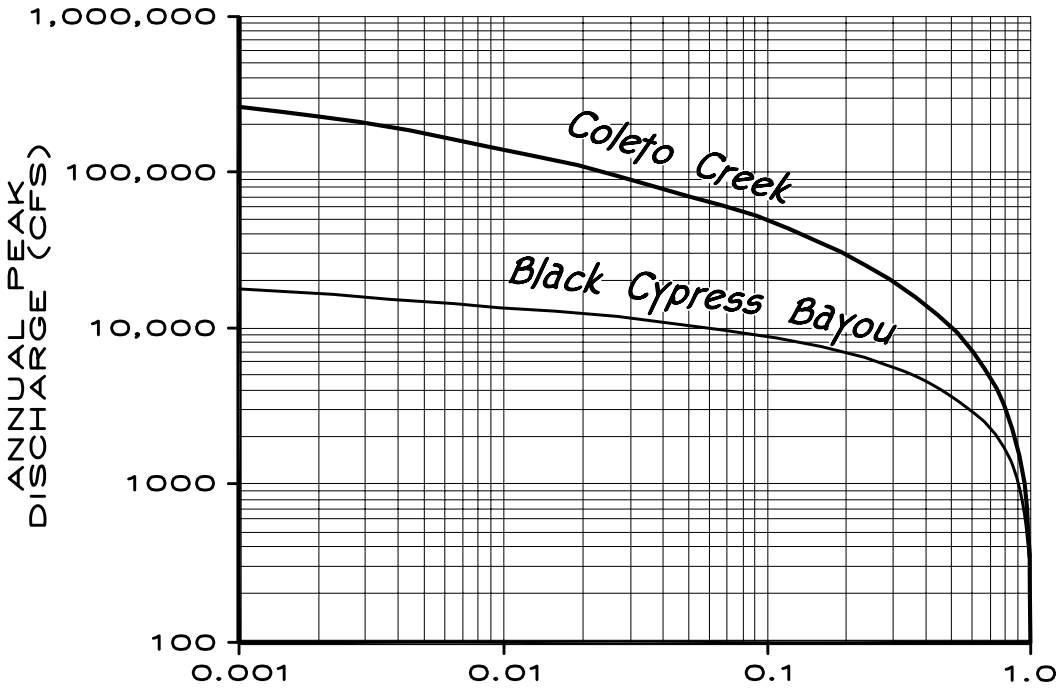


Figure 1.50. Estimated Peak Discharge Frequency for Coleto Creek and Black Cypress Bayou. This log-log graph shows the probability of a given peak discharge (in cubic feet per second) for both streams based on available historical records (1930-1979 for Coleto Creek, 1969-1993 for Black Cypress Bayou) and was generated using PEAKFQ, a computer program produced by the USGS (Slade and Asquith 1996). It shows that Coleto Creek has higher peak discharges and a higher probability of a given peak discharge.

Although this characterization is accurate, I suspect that historic land clearance has simply exacerbated a trend already underway when the earliest non-Indian settlers arrived. Perdiz arrow points were recovered from the upper 30 cm of post-Beaumont sediments at Berger Bluff, and four potsherds from the upper 15 cm. Similar artifacts have been radiocarbon dated elsewhere in south Texas at 1300 to 1600 AD. Little or no

sediment accumulated over these artifacts after they were discarded. Probably all were deposited near the present ground surface, with some having been displaced downward by bioturbation. This implies aggradation had ceased by Late Prehistoric time, otherwise a recognizable sterile deposit would have accumulated over these Late Prehistoric markers. Moreover, if the upper meter of post-Beaumont sediments are even partially eolian in origin (as suggested by Glen Evans), a metamorphosis to a wide, sandy, seasonally desiccated channel is implied, perhaps as early as the Late or Middle Archaic (the date cannot be specified with any more precision because no radiocarbon dates are available from the upper deposits, and few diagnostic artifacts were recovered below one meter in depth). In any case, it seems highly probable that downcutting began whenever the present channel form, adapted to flashy and potentially erosive discharge, was assumed.

If we examine historical accounts of Coleto Creek to try to determine the earliest date at which the present channel form appears, the data are no more precise than the archeological evidence. Limited settlement probably began along lower Coleto Creek soon after establishment of the De Leon colony in the early 1820's, but most of the Berger Bluff catchment appears to have remained unsettled until after about 1845, when German immigrants landing at Indianola began to occupy the basin. Major land clearing in the Coleto basin may be presumed to date after this initial wave of settlement (see Biesele 1930). Most of the cleared land is now in pasture rather than cropland, and forms a mosaic pattern that can be recognized on USGS maps or satellite imagery. In comparison to the upper part of the catchment, the post oak belt near the site is less affected by clearing.

After the founding of Victoria in 1824, travel between Victoria and La Bahia (Goliad) became frequent, passing along a route approximated by Highway 59, so there are a number of early descriptions of Coleto Creek at a point near the present Highway 59 bridge at Raisin. Unfortunately most of these are too vague to be of much help.

One of the earliest descriptions is that of Stephen F. Austin, on his first trip to Texas. In August, 1821, Austin traveled from Goliad toward the future site of Victoria and made the following journal entry:

> Monday 3d...came out 4 miles to a Creek where the company encamped — clear runing [*sic*] water, land good but rather sandy [this presumably was Manahuila Creek] — in the afternoon came on 12 miles to the Colato Creek a large bold stream of clear runing water land generally good, in some places too sandy, considerable quantity of oak timber....(Austin 1903:299).

Berlandier also crossed Coleto Creek in both directions in February, 1829, but says only that "...piles of sand...are common on the banks of the stream named Coleto...." (Berlandier 1980:552).

One of the early guidebooks for Texan immigrants, Moore's *Map and Description of Texas* (1840), says:

> The Coleto empties into the Gaudalupe [*sic*] a few miles below Victoria. It is a beautiful stream of clear and wholesome water, and is distinguished for the remarkable beauty and fertility of its banks (Moore 1840:134).

In 1841 Thomas Falconer recorded:

> At the distance of about six miles from Victoria we crossed the Rio Coleto, the banks of which for a considerable distance are of light white sand (Falconer 1843:202).

In March, 1844, Auguste Fretelliere, an immigrant traveling inland from Victoria, noted:

> After crossing a little stream [presumably Dry Creek], we came for the second time to an immense prairie, on which the verdure was magnificent and the bogholes less frequent. Although we were in the first days of March the sun was disagreeably hot, and we were always very thirsty. The horizon with its mirages represented a lovely sheet of water which seemed to retreat as we went forward. Finally, toward sunset we camped on the bank of a creek called the Colette. The water was crystalline and rushed over a bed of white sand. You will believe that we waded in with delight. An hour after colic and nausea taught us, to our cost, that we must not always rely on appearances (Waugh 1934:89).

In October, 1846, another traveler named Furber recorded, "We marched over a pleasant country, but rather scarce of timber, and at noon encamped on a clear, rapid stream, called the Colette" (Furber 1848:145).

The most detailed of these historical accounts is that of John Bartlett, traveling with the International Boundary Commission in 1850, from Victoria to Goliad. Bartlett wrote,

> ...I left Victoria on the 13th, with the larger portion of the Commission, and formed my camp in a beautiful grove of live oaks, on the banks of the river Colette... September 14th...The banks of the Colette are overhung with trees, from the branches of which hang long festoons of moss, waving gracefully with the breeze. The river is about 150 feet wide, and near our camp about five feet deep and quite sluggish. Saw many fine fish, among them the kind known as the `buffalo fish'...." (Bartlett 1965:18-19, 21).

In 1853 Brevet Lieutenant Colonel W. G. Freeman took a different route inland from Victoria, passing across the Berger Bluff catchment. Not referring specifically to Coleto Creek, but to the streams in the area generally, Freeman observed,

> Leaving Indianola at 4 p.m., May 26th, I proceeded via Lavaca, Victoria, Yorktown and the Sulphur Springs, to San Antonio....Ocasionally trains are kept back, involving sometimes the loss of animals, by the swelling of the streams on

> the route, which in this country frequently rise twenty feet in a few hours, but the waters subside almost as rapidly, and such detentions rarely exceed two days (Malsch 1977:90).

While none of these historical accounts spanning the years 1821-1853 is detailed enough to permit an accurate reconstruction of the hydrologic regime of early nineteenth century Coleto Creek, it is important to note that all are at least consistent with the idea that the creek had already taken on its present form. Most accounts mention clear water and clean white sand, indicating the Coleto carried little suspended load and was choked with a heavy sand bedload as it is now. The account by Bartlett indicates the creek was about 45 meters wide, and at the point described, evidently a slackwater pool, was about 1.5 m deep and large enough to support a population of buffalo (presumably *Ictiobus bubalus*).

Other records from the second half of the nineteenth century, as German settlement was spreading over the Coleto basin, show how clearing and grazing began to reinforce the already rapid throughflow potential of the creek. Early church records from Meyersville, translated from the original German, are a valuable source of information from the beginning of the Civil War into the twentieth century (Jacob and Egg 1978). While these records contain no really detailed accounts of the local environment, there are brief notations for almost every year. The nature of the land at the beginning of settlement is indicated in an entry I have already quoted in the section on vegetation, but which is worth repeating here:

> More settlers came and settled on the right and the left banks of the Twelve-Mile Coleto, especially in the years from 1855-1859. The raising of cattle became especially profitable because of the grass which in the beginning of the settlement was so tall that it was almost impossible to walk in (Jacob and Egg 1978: 4).

There followed a severe drought at the beginning of the war, especially in the years 1860, 1862, and 1863. The entry for 1860 reads,

> The year 1860 was a hard year ....From May 22 until August 7, no rain fell. Consequently the grass dried entirely and the springs and brooks stopped flowing, so that the oldest settlers stated that there had not been such a drought within the last 20 years (Jacob and Egg 1978:11).

The combination of recurrent drought and grazing by cattle depleted the ground cover during these years, so that when a major storm track crossed the Coleto basin in the spring of 1865, severe flooding followed:

> During the night of March 26 a terrible storm struck. The rain came down in torrents and lasted until midnight....The water overflowed the banks of the Coletto and washed away fences. The homes of Mr. P. Walker and Mr. Kohler were torn loose from their foundations and were washed away (Jacob and Egg 1978:18).

In summary, archeological evidence suggests floodplain aggradation had ceased and channel incision began by the Late Prehistoric, but perhaps as early as the Middle to Late Archaic. The reversion from aggradation to incision presumably documents the passing of a geomorphic threshold as a result of increasingly flashy, erosive discharge; and it was presumably at the same time that Coleto Creek assumed its present channel form: wide, shallow, sand-choked, with chutes colonized only by fast-growing pioneer plant species. The historical accounts, sketchy as they are, nevertheless suggest this channel form was already in existence well before the first significant wave of land clearing by German settlers after 1845. Moreover, it seems unlikely Coleto Creek would be able to hew its way through the nine meters of sediments at the bluff in just over a century. More probably, historic land clearance has simply accelerated an erosional regime that was already well established before the earliest Euroamerican settlement.

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Chapter 2: The Guadalupe-San Antonio River Basins at the End of the Younger Dryas

INTRODUCTION

The first chapter reviewed the nature of global environmental change at the transition from the Pleistocene to the Holocene, and sketched the contemporary appearance of the study area. This chapter will narrow the focus in both time and space, looking at paleoenvironmental data from the end of the Younger Dryas (Fig. 2.0), and reviewing other sites in the Guadalupe and San Antonio River basins that have furnished proxy data. First, however, we must address some radiocarbon assay problems.

In my quest to find out what was happening to regional environments at that time, I have had to slog through an expansive and often murky cienega of literature, and now I find I must drag the reader behind me. Trying to review the various contradictions, omissions, and inconsistencies of the empirical record makes for tedious reading indeed in this chapter, but the reader must follow the same trail in order to understand just what the limitations are.

CHRONOMETRIC CONVENTIONS

Kinds of years

Much of Chapter 1 discussed polar ice cores. The upper parts of these cores can be dated by counting summer layers (Dawson 1992:19), much like tree rings, at least as far back as 8000 years ago. Counts back to 8000 BP are made by looking for seasonal isotope peaks; detection of seasonal peaks in acid and dust content can further extend the

annual counts somewhat beyond the Pleistocene-Holocene boundary. Below that point, compression and distortion from the weight of accumulated ice has smeared the layers, and dating must rely on calculations of accumulation rate using ice-flow models.

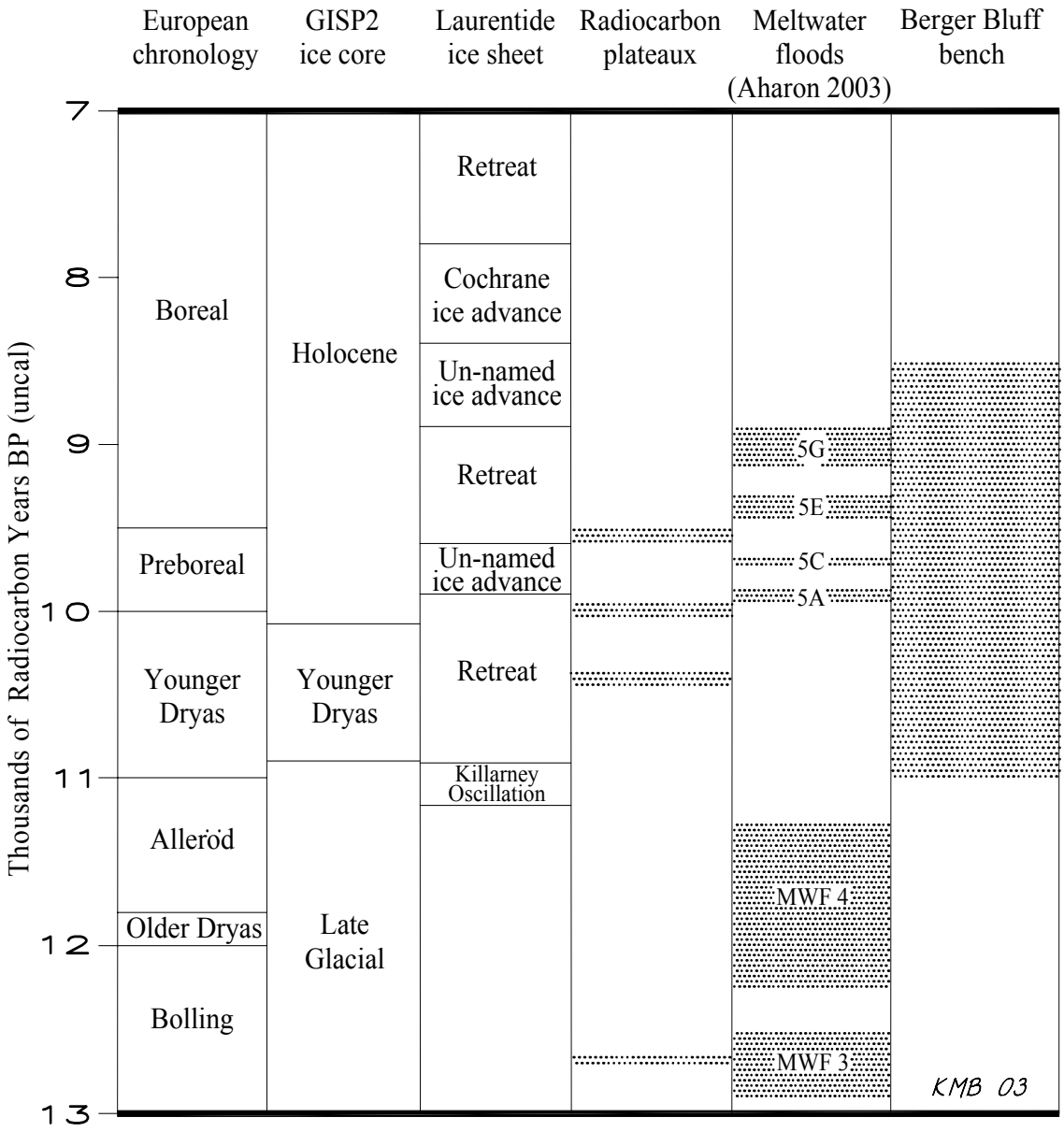


Figure 2.0. Chronology of the Pleistocene-Holocene Transition.

In any case, *ice-core years* are roughly equivalent to *calendar years*. Actually, Jerrard and McNeill (1992:188-190) define several different kinds of years (tropical, sidereal, astronomical, Gaussian, mean solar, calendar year), but the differences are trivial at an archeological scale. I will use the terms *calendar year* or *sidereal year* interchangeably to refer to years marked by passage of the earth around the sun. For practical purposes, years of this kind can be considered equivalent to calibrated radiocarbon years, and I will use the term "cal BP" to refer to calendar years before present, where "present" is defined by convention as the radiocarbon zero point of AD 1950. The reader may think of "cal" as an abbreviation for either "calendar" or "calibrated". The term "uncal BP" refers to *uncalibrated radiocarbon years before present*, and the abbreviation RCYBP refers to "radiocarbon years before present." The GISP ice core record extends up to the year 1989, but the zero point is set at AD 1950, so as to synchronize it with the radiocarbon zero point (1989 is considered "minus 39 years BP" in the ice core chronology).

Because students of the paleoenvironment deal in so many different kinds of years (ice-core years, varve years, uncalibrated and calibrated radiocarbon years), researchers are obligated to state explicitly what kinds of years they are using, and where the zero point is fixed. Unfortunately, few honor this obligation. Even today, much of the literature in leading journals such as *Nature* or *Science* is opaque where such details are concerned. Comparing timescales measured in different kinds of years can lead to serious error.

Because the Greenland ice cores furnish what is clearly the best and most detailed proxy record for the transition to the Holocene, it is inevitable that the ice core record

should be proposed as the stratigraphic yardstick for this period. Bjorck and others (1998) have proposed a climatic event stratigraphy for the North Atlantic region based on the GRIP ice core, with the Holocene beginning at 11,500 ice core years BP (roughly 10,090 RCYBP).

The sidereal (or calendar year) timescale is obviously the best and most parsimonious timescale, but because so much of the existing paleoenvironmental literature is scaled in terms of radiocarbon years, I have adopted the *uncalibrated radiocarbon timescale* as a standard for this study. The calibrated radiocarbon timescale cannot be used because there is no such thing as a "final" calibration; calibration systems are being improved constantly. In the present work, if kinds of years are not specified, then uncalibrated radiocarbon years are implied.

The radiocarbon timescale

Unfortunately, the uncalibrated radiocarbon timescale is a distorted one. We know these distortions of the radiocarbon timescale are present because in cases where AMS dating of individual tree rings or macrofossils from lake varves has been compared with dates independently derived by ring-counting or varve-counting, there are segments where the paired age estimates are offset (Goslar *et al*. 1995; Hadjas, Ivy-Ochs, and Bonani 1995:Table 1). What accounts for these deviations?

Two key assumptions on which Libby based the radiocarbon method are that 1) the rate of radiocarbon production in the atmosphere has been constant throughout the past and 2) the rate of exchange between the biosphere (including the oceans) and the atmosphere has been rapid and constant. We now know that neither of these assumptions

is entirely true. Atmospheric radiocarbon content, or *delta* ^{14}C, which Stuiver and others define as "the relative deviation of the measured ^{14}C activity, after correction for (1) radioactive decay related to age and (2) isotope fractionation, from the..." [oxalic acid standard] (Stuiver *et al*. 1991:2) has been relatively low during warm periods and higher at the onset of cold periods during the late Quaternary (van Geel, van der Plicht, and Renssen 2003). It declines dramatically from the Late Glacial period through the Holocene until the last millennium (Fig. 2.1; and Stuiver *et al*. 1991:Fig. 1). Various measurements from corals and wood suggest that the radiocarbon declined from about 230 ‰ at about 13,500 RCYBP to about -15 ‰ at about the year AD 430 before rising again to present values. According to Stuiver and others (1991), the decline is due chiefly to changes in intensity of the earth's geomagnetic field, modulated at certain times (such as the Younger Dryas) by changes in oceanic ventilation. At the Pleistocene-Holocene boundary, this translates to an age offset of a millennium or more between calendric and radiocarbon ages. Stuiver and Braziunas (1993) maintain that the high radiocarbon values before 15,000 BP were due to lower geomagnetic dipole intensity, and that no major changes in oceanic ventilation rates occurred after 12,500 BP (Stuiver and Braziunas 1993:146, 150).

The second of Libby's assumptions — constant exchange of carbon between the oceans and atmosphere — is a particular problem, since the world's oceans contain more than 90% of its ^{14}C inventory. Oceanic mixing or ventilation rates have varied at times during the past. Periods of reduced upwelling can cut off the supply of "dead" carbon (^{12}C) from the deep ocean, making the radiocarbon content of the atmosphere appear younger than it otherwise would. Since new ^{14}C continues to be produced in the upper atmosphere, the $^{14}C/^{12}C$ ratio in the atmosphere is temporarily enhanced beyond the normal ratio, and any organic material that incorporates that radiocarbon will produce a

spuriously young radiocarbon age. Stocker and Wright (1996:789) estimate the increase in atmospheric ^{14}C is on the order of 35 ‰ whenever the North Atlantic branch of the "conveyor" is interrupted. Further complicating the picture, a significant fraction of the world's terrestrial carbon inventory was transferred to the ocean when rising Holocene sea level covered previously exposed continental shelves (Faure *et al*. 1996). This will also have to be incorporated in future models.

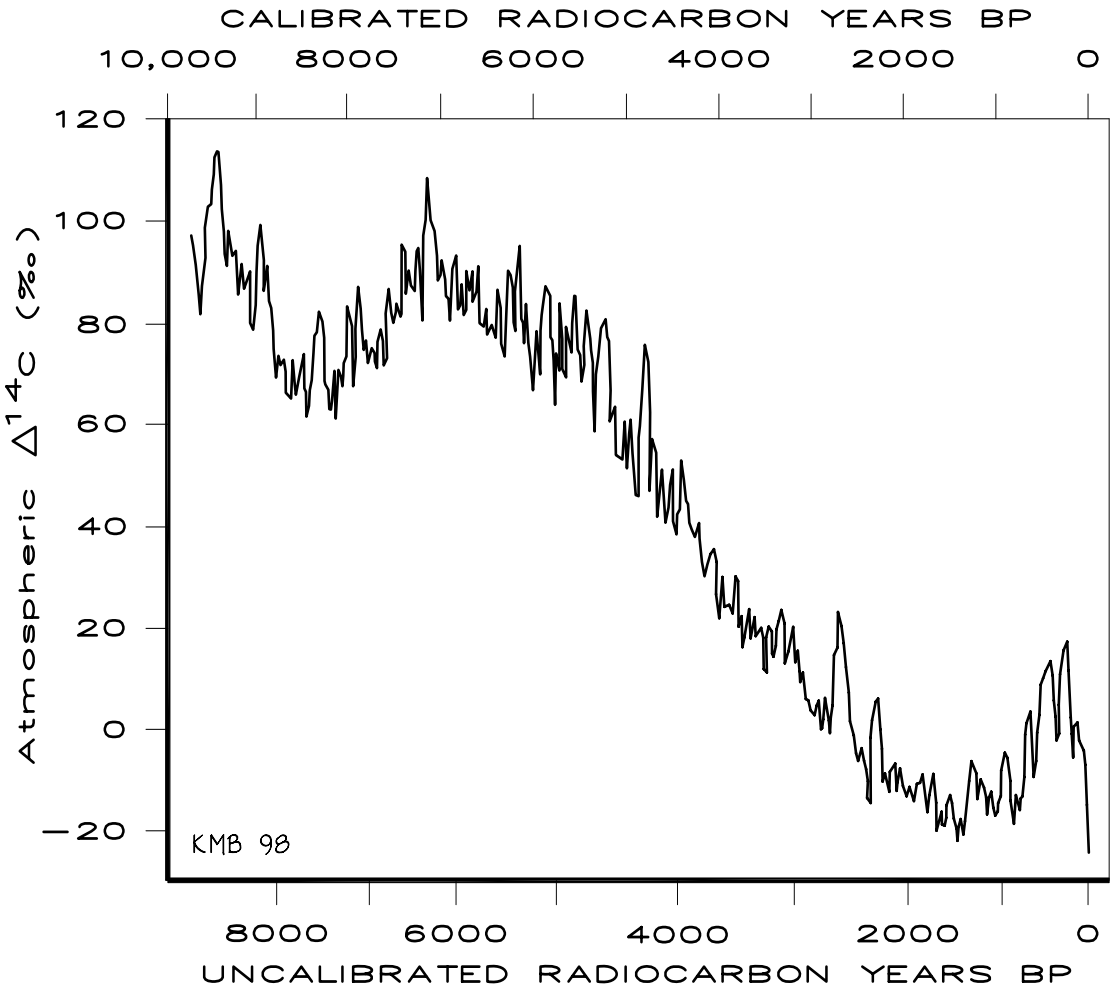


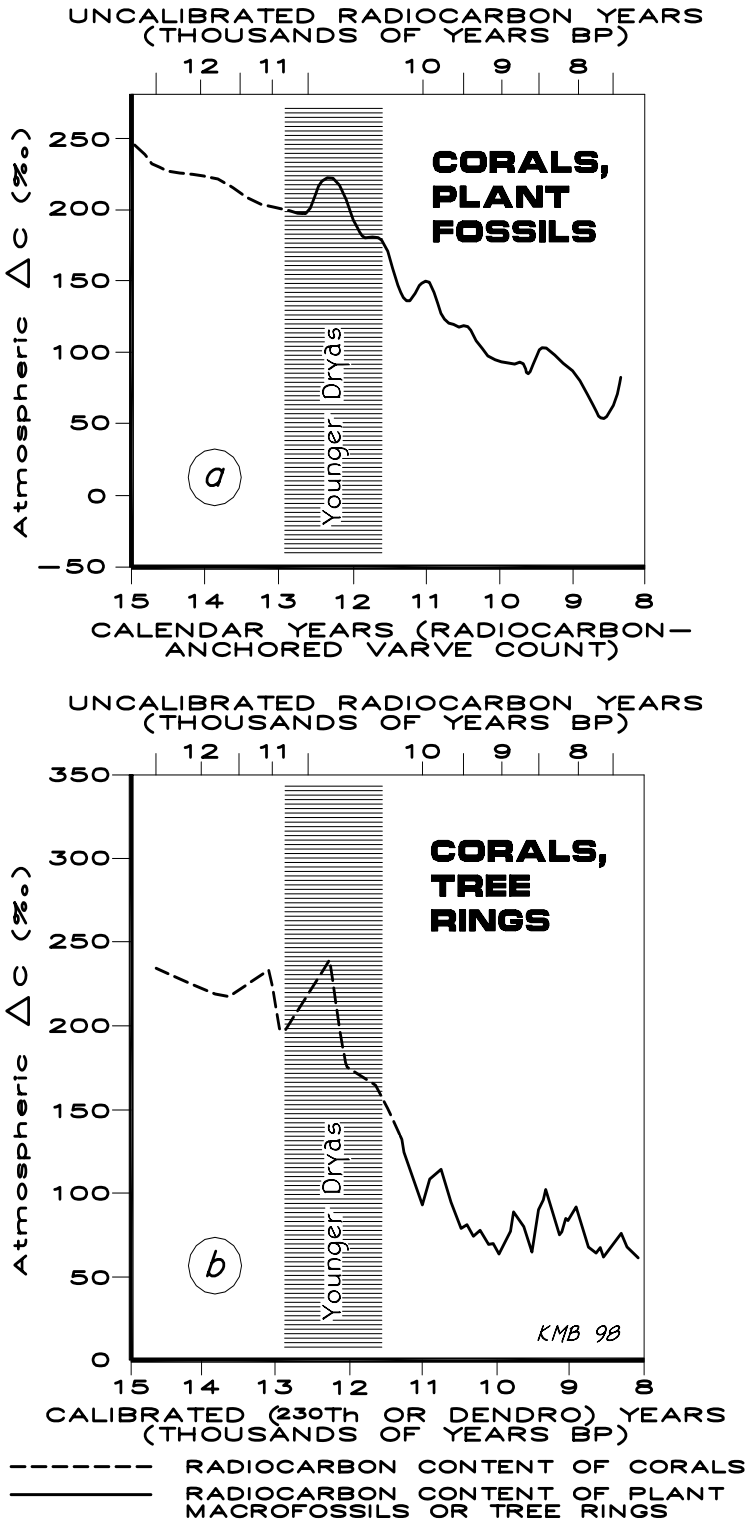
Figure 2.1. Atmospheric Radiocarbon Content in the Holocene. Delta ^{14}C values, in per mil units, from 10,000 cal BP (about 9050 RCYBP uncal) to the present, adapted from Stuiver *et a*l. (1991:Fig. 1). Long-term decline is driven by geomagnetic field intensity.

Radiocarbon samples from marine sources are also affected. Although common practice now is to include an invariant "marine reservoir effect" of about 400 years to allow for the greater proportion of dead carbon in the oceans, the reservoir effect has varied in the past according to the history of thermohaline circulation. Kroon and others (1997:758), for example, estimate a reservoir effect of about 700 years during the Younger Dryas. Although it is clear that the $^{14}C/^{12}C$ ratio has varied during the Quaternary, there are major differences of opinion on the relative importance of geomagnetic field changes and changes in ocean ventilation rates. Stuiver and Braziunas see geomagnetic field changes as the principal variable, with changes in ocean circulation playing a minor role, at least during the Holocene. Stocker and Wright see ocean circulation playing a major role in creating radiocarbon age plateaux (see also Goslar *et al*. 2000, Hughen *et al*. 2000, and Muscheler *et al*. 2000). Others see changes in solar activity and cosmic ray intensity as the principal cause (van Geel, van der Plicht, and Renssen 2003) – that is, short-term fluctuations unrelated to the longer-term insolation trends discussed in Chapter 1.

Atmospheric radiocarbon content was especially variable during the Pleistocene-Holocene transition. Based on paired radiocarbon and uranium/thorium assays of corals from the Huon Peninsula in Papua New Guinea, Edwards and others estimate that atmospheric $\delta\ ^{14}C$ actually dropped somewhat at the beginning of the Younger Dryas, then rose slightly, then dropped sharply during the latter half of the Younger Dryas (Fig. 2.2, *B*, adapted from Edwards *et al.* 1993:Fig. 5). Goslar and others (1995) have compiled a similar curve using varve counts and AMS dated plant macrofossils from sediments in Lake Gosciaz in Poland. Their curve begins at about 11,000 RCYBP and shows $\delta\ ^{14}C$ rising abruptly at the onset of the Younger Dryas to a peak, then declining thereafter (Fig. 2.2, *A*, adapted from Goslar *et al.* 1995:Fig. 4). See

also Goslar and others (2000:Fig. 3). Varve counts and radiocarbon dated foraminifera in a marine core from the Cariaco Basin (offshore Venezuela) show the same thing (Hughen *et al*. 2000:Fig. 3), as do radiocarbon-dated macrofossils from Kodiak Island, Alaska (Hadjas *et al*. 1998). Confirmation of these curves also comes from AMS-dated macrofossils in varved sediments of Lake Suigetsu, Japan (Kitagawa and van der Plicht 1998).

Figure 2.2. Atmospheric Radiocarbon Content at the Transition to the Holocene *(following page)*. *A*, composite curve based on radiocarbon of Barbados corals (dashed line) and AMS-dated plant macrofossils from Lake Gosciaz, Poland (solid line), adapted from Goslar *et a*l. (1995:Fig. 4); see reference for details. *B*, composite curve based on radiocarbon of Barbados and Huon Peninsula corals (dashed line) and AMS-dated tree-rings (solid line), adapted from Edwards *et al*. (1993:Fig. 5). Younger Dryas span derived from GISP2 ice core, not cited sources. Note effect of rapidly changing radiocarbon content on uncalibrated time scale.


UNCALIBRATED RADIOCARBON YEARS
(THOUSANDS OF YEARS BP)
12 11 10 9 8
Atmospheric Δ C (‰)
250 200 150 100 50 0 −50
CORALS, PLANT FOSSILS
Younger Dryas
a
15 14 13 12 11 10 9 8
CALENDAR YEARS (RADIOCARBON—ANCHORED VARVE COUNT)
UNCALIBRATED RADIOCARBON YEARS
(THOUSANDS OF YEARS BP)
12 11 10 9 8
Atmospheric Δ C (‰)
350 300 250 200 150 100 50 0
CORALS, TREE RINGS
Younger Dryas
b
KMB 98
15 14 13 12 11 10 9 8
CALIBRATED (230Th OR DENDRO) YEARS
(THOUSANDS OF YEARS BP)
RADIOCARBON CONTENT OF CORALS
RADIOCARBON CONTENT OF PLANT MACROFOSSILS OR TREE RINGS

The raw radiocarbon timescale is a compressed and distorted one, like a long ribbon with small sections that are folded back upon themselves. Changes in ocean ventilation rates can produce a *plateau* (a period during which calendar years march onward, but the radiocarbon clock appears to stand still) or even small-scale inversions in the radiocarbon age. Calibration is the procedure that pulls on the ends of the ribbon to stretch it out to its true calendric length. Any archeologist who has used calibration programs like CALIB or OXCAL has probably noticed that there are time spans during which the calibration procedure will produce multiple solutions, or in some cases the calibrated age will become slightly *younger* as the raw radiocarbon is increased. These are periods when either production or ventilation rates are in flux. Since mode-switching of thermohaline circulation appears to influence both climatic changes and the pace of the radiocarbon clock, ambiguity of radiocarbon dates may occur exactly at those points where close-interval dating is needed to clarify rapidly changing paleoclimate systems.

Apart from the problems of radiocarbon plateaux, another example of the precision limits of radiocarbon dating is Michigan's Gribben Forest, an entire spruce forest buried in sand deposited by glacial outwash after the retreat of the Marquette Re-Advance in the early Holocene. The outer rings of four different spruce trees were AMS dated at, respectively, 9660±60, 9830±70, 9930±70, and 10,290±90 RCYBP (11,155 to 12,103 cal BP; Pregitzer *et al*. 2000:Table 1). Burial was presumably a simultaneous event, but in this case, the means of the raw assays differ by up to 630 years, and the 10,000 BP radiocarbon plateau introduces even further ambiguity.

Known radiocarbon plateaux

The present study of the bench deposits at Berger Bluff concerns chiefly the period of 8500-11,000 uncalibrated radiocarbon years before present (uncal RCYBP). There are known radiocarbon plateaux centered at about 12,700, 10,400, 10,000, and 9600 to about 9500 uncal RCYBP (Wohlfarth 1996:280, Fig. 1; see also Kromer and Becker 1992:Fig. 3b, Kitagawa and van der Plicht 1998:1188). These show up clearly, for example, in the radiocarbon-dated varve sequence at Rotsee, Switzerland (Lotter, Ammann, and Sturm 1992:Fig. 2). As the chapter on radiocarbon dating will show, only one of the assays from the bench area falls in the 10,000 RCYBP plateau.

THE YOUNGER DRYAS: GLACIAL REPRISE

After the height of the Wisconsinan glaciation at 18,000 RCYBP uncal, there was rapid warming in many parts of the world from 13,000-11,000 RCYBP uncal (known in the deglacial chronology as *Termination 1a*), then an abrupt cool episode known as the *Younger Dryas* at about 11,000-10,000 RCYBP uncal, then resumed rapid warming (*Termination 1b*), the Holocene, after 10,000 RCYBP uncal [Kennett 1990, Mathewes *et al*. 1993; Reasoner *et al*. 1994; note that Broecker (1992), Hammer and Clausen (1986), and Mix (1987: Fig. 16) give slightly different figures]. Figure 2.0 shows how this event appears in marine and ice cores. Terminations 1a and 1b are marked by meltwater pulses entering the world's oceans, while the Younger Dryas is marked by a halt (or in some cases even a readvance) in the retreat of glaciers. The Younger Dryas (also known in the ice core chronology as Greenland Stadial 1, or GS-1) has always intrigued paleoclimatologists because it is too short, begins too rapidly, and ends too rapidly to be a result of astronomical forcing. Alley (2000) reviews its appearance in the Greenland ice cores.

The Younger Dryas is foreshadowed in New Brunswick, Nova Scotia, and Maine by a 250-year-long "precursor" cooling event known as the Killarney Oscillation, presumably associated with the Gerzensee Oscillation in Switzerland. It has also been detected at Crawford Lake, near Ontario, shortly before 11,000 RCYBP (Yu and Eicher 1998). The Killarney Oscillation lasts from 11,160 to 10,910 RCYBP (Levesque *et al.* 1993; Cwynar and Levesque 1995). In the Canadian sites, it is separated from the Younger Dryas by a very short warmer period, but at its end nearly coincides with the beginning of the Younger Dryas as it is dated elsewhere (see below). The Killarney Oscillation has not been widely recognized elsewhere, most likely because other students have not used the 0.5-1.0 cm sampling resolution employed by the Canadian researchers. They estimate a drop in summer water surface temperature of about 4° C during the Killarney Oscillation and about 7° C during the Younger Dryas (Levesque *et al.* 1993:Fig. 3). Fossil beetle data from Nova Scotia and New Brunswick suggest July temperatures about 0.5° C above to 5.3° C below modern, and January temperatures about 7-17.9° C below modern in the early Younger Dryas (10,600-11,100 RCYBP; Miller and Elias 2000:Table 2). Chironomid data from Splan Pond suggest a 2.5-4.5° C drop in July temperatures at the onset of the Younger Dryas, and an abrupt rise of 6.0-6.5° C at its end (Lotter *et al*. 1999). The Killarney Oscillation ends at about the same time as Vance Haynes's "Clovis drought," although the relationship between the two is unknown.

Dating the Younger Dryas

The Younger Dryas climatic signal has been recognized in the Greenland ice cores, in lake varves, in marine sediments, and various other kinds of sites. Age estimates

for the beginning and end, however, vary according to local dating problems. As a result, there is still some lingering uncertainty as to whether this event is synchronous worldwide, or whether discrepancies in age estimates are merely due to local dating problems. For example, Goslar *et al*. (1995) estimated the end of the Younger Dryas at 11,440±120 cal BP, which is about 220 years later than the estimate from the GISP2 ice core. However, their estimate comes from varved sediments in Lake Gosiacz in Poland, and because the upper part of the core is poorly laminated, the chronology is considered "floating" at the upper end. Hajdas and others (1995:77) place the YD/Pre-Boreal transition at about 11,000 calendar years BP, and the length of the YD at about 1140 years, based on varve-counting at Soppensee, Switzerland. Other estimates from European records seem to lag as much as 800-900 years behind the Greenland ice core signal (Stromberg 1994; Bondevik and Mangerud 2002). Likewise, the Younger Dryas shows up in cores from Owens Lake, California, but a 500-year error factor in age estimates makes it impossible to demonstrate synchroneity (Benson *et al.* 1997. As Lowe and others (1995) point out, some of the dating difficulty derives from the fact that the onset of the period is time-transgressive, for example affecting England somewhat earlier than northwestern Germany (see also Ruddiman and McIntyre 1981:Fig. 26).

Most of the earlier estimates put the beginning of the Younger Dryas at about 12,700 calendar years BP and its end at 11,500 calendar years BP (Johnsen *et al.* 1992:Table 1; Alley *et al*. 1993:Table 2; Goslar *et al*. 1995; Björck *et al*. 1998). Björck *et al*. (1996) put the end at 11,450 to 11,390±80 calendar years BP. For a recent comprehensive list of estimates of the beginning and end of the Younger Dryas, see tables 2 and 1, respectively, in Goslar, Arnold, and Pazdur (1995).

The most recent, and probably most accurate estimate of the end of the Younger Dryas comes from the GISP2 core, where the YD/Preboreal transition appears to start at 11,645 calendar years BP (Taylor *et al.* 1997:826). The most recent estimate of the start of the Younger Dryas appears to be 12,820±260 calendar years BP (Goslar, Arnold, and Pazdur 1995:Table 2), although the beginning is not as well defined as the termination. The best estimate of YD duration appears to be about 1300±70 calendar years (Alley *et al.* 1993).

These estimates correspond roughly to an inception date of 10,897 radiocarbon years BP uncal and a termination of 10,091 RCYBP uncal, with a duration of roughly 800 uncalibrated radiocarbon years.

In terms of the chronology of the Berger Bluff bench deposits, this means that at least part of the lowest sediments in the bench probably date to the Younger Dryas (although it is difficult to be specific because the lower part of the section is poorly dated), while the middle to upper parts of the bench stratigraphy probably encompass all of the Preboreal and part of the Boreal periods.

The Younger Dryas should be of particular interest to archeologists because a large part of the known, radiocarbon-dated Paleoindian archeology in North America dates from this period of climatic change. It begins at about the same time as the earliest dated Folsom components, but ends either somewhat before or after the latest Folsom components, depending on whether one chooses to rely on the ice core evidence for dating, or some other kind of record. The time relationship of Clovis components to the Younger Dryas is more difficult to specify, simply because Clovis components are so poorly assayed. Some of the younger Clovis assays apparently overlap with the

beginning of the Younger Dryas as well (see Roosevelt 1998). Likewise, radiocarbon dates from the Goshen component at the Mill Iron site straddle the beginning of the Younger Dryas, although most of them are slightly earlier (Frison 1996:Table 1.1). The association of these well-known Paleoindian complexes (Folsom certainly, Clovis, Goshen, and Dalton possibly) with this dramatic episode of climate change certainly has behavioral, if not deterministic implications.

Equally interesting is the fact that several Paleoindian occupations of equivalent age are known from the northeastern US and Canadian maritime provinces, the area where the Younger Dryas is best documented in the western hemisphere. This area clearly was not abandoned during the Younger Dryas climatic reversal (Roberts 1984, Keenlyside 1991). Although few Paleoindian sites in this region have radiocarbon assays, the Debert (MacDonald 1968), Hiscock (Laub 1995), Whipple (Locus B, Curran 1984:13), Vail, and Shawnee-Minisink sites (Haynes *et al*. 1984:Table 2; Gramly 1982:60) fall within the Younger Dryas time span. The Michaud site may perhaps also be included, although it has discrepant assays on Feature 7 (Speiss and Wilson 1987:83-84). The Vermilion Lakes site in Alberta also has early archeological components (Group 1, 10,800 to 10,300 uncal BP) with evidence of mountain sheep hunting and a possible windbreak or shelter. Although pollen is lacking from those components, it was recovered from underlying sediments and from 20 km away at Copper Lake, and the evidence suggests a Younger Dryas climatic signal to the excavators (Fedje *et al*. 1995:100-102).

Origin of the Younger Dryas

Wallace Broecker is perhaps the principal advocate of a thermohaline circulation model for the origin of the Younger Dryas (Broecker *et al*. 1988; Broecker 1994, 1995,

1997; Wright 1989). According to this model, increasing insolation at high latitudes in the Late Glacial period produced substantial meltwater, mostly from the Laurentide, but also from the Fennoscandian ice sheet. Once the Laurentide sheet retreated sufficiently, meltwater was routed eastward through the St. Lawrence seaway instead of the Mississippi River. This produced an extensive cap of fresh water over the North Atlantic, an area where previously very dense, saline water was produced.

This dense, saline water (North Atlantic Deep Water, or NADW) normally sinks to the ocean depths, flowing southward, and is replaced by less saline surface water that flows northward in the Gulf Stream, bearing considerable heat from the equatorial region. It is this northerly-redistributed heat that maintains Europe's maritime climate. According to Broecker, disruption of this "conveyor" system by meltwater in the Younger Dryas was responsible for cold climate both over the North Atlantic itself and the bordering regions of Europe and North America. Broecker proposed a sort of "mode-switching" in which NADW production shut off during cold episodes (Broecker, Peteet, and Rind 1985). Some recent modeling studies (Fanning and Weaver 1997; Fawcett *et al*. 1997) support the Broecker model.

Various challenges to this model have been issued. Jansen and Veum (1990), for example, maintain that there was actually an increase in NADW production during the Younger Dryas proper. Webb *et al*. (1997) use GCM modeling to suggest that glacial-age ocean heat transport was similar to modern rates, but changed CO_2 levels led to enhanced cooling (presumably this applies to the Younger Dryas as well). Studies of salinity history in three marine cores at the outlet of the Gulf of St. Lawrence show meltwater pulses before and after the peak of the Younger Dryas (especially at 10,210

RCYBP), but indicate reduced melting during the peak; moreover, the freshening effect of meltwater was confined to the uppermost water layer and vanished before reaching the continental shelf break (De Vernal, Hillaire-Marcel, and Bilodeau 1996). This is supported by analysis of marine cores across the North Atlantic by Duplessy, Labeyrie, and Paterne (1996), who likewise find no evidence of meltwater presence during the Younger Dryas. These findings seem particularly damaging to the Broecker model (see also Moore *et al*. 2000). Other studies challenging the thermohaline model have focused on the role of intermediate water (Boyle and Keigwin 1987; Rahmstorf 1994; Smith *et al*. 1997). Berger and Jansen (1995) dispute the NADW-production model and propose an alternate model which they call the "super-fjord heat pump" and assert that

> deglaciation is a phenomenon that has to do with the collapse of ice; thus, it is largely a problem in glacial geology. The Younger Dryas, a pause in deglaciation, also is a problem of glacial geology, therefore (Berger and Jansen 1995:93).

Renssen and others (2000) offer an even greater departure, suggesting that the Younger Dryas was triggered by a reduction in solar irradiance.

Geographic extent

A consensus has long prevailed that the Younger Dryas was essentially a circum-North Atlantic phenomenon. It was thought to be best expressed in the maritime regions of western Europe and eastern Canada (Miller 1996, 1997), becoming less well defined toward the continental interiors (Wright 1989:298; Yu and Wright 2001); cooling was thought to be marked in Europe but minor in eastern North America (Wright 1989:300). In 1992, Dorothy Peteet published a map showing the pollen record of the Younger Dryas, present only in the northeast, and absent in the rest of the United States (Peteet 1992:Fig. 1). The most comprehensive geographic review of pollen-based Younger Dryas

climatic signals was published by Rind and others (1986). Their review also showed an absence of evidence in the North American continental interior, including the three palynological sites they list for Texas: Crane Lake, Bonfire Shelter, and Boriack Bog. Their computer simulation of Younger Dryas climatic change yielded only very small departures from present-day conditions for the central United States — a 0.8° C drop in average annual temperature, an increase in precipitation of 0.1 mm per day, and an increases of P-E (precipitation minus evaporation) of 0.2 mm per day (Rind *et al*. 1986:Table 9). A more recent and still more comprehensive review of modeling and empirical evidence suggests about a 3° C reduction in mean annual air temperature from the present (Rutter et al. 2000:Fig. 2) in Texas.

However, more recent studies have found evidence of Younger Dryas cooling in various parts of the world far removed from the North Atlantic (Dawson 1992:104-105). Reassessments of the North American evidence by Peteet in 1995 found a wider "footprint" (Peteet 1995a, 1995b) than in her 1992 survey. Younger Dryas signals have been found at Crawford Lake and Twiss Marl Pond near Toronto (Yu and Eicher 1998), at Crowfoot Lake and Bow Lake in Alberta (Reasoner, Osborn, and Rutter 1994), at Canandaigua Lake, New York (Wellner and Dwyer 1996), in Connecticut and New Jersey (Peteet *et al*. 1993), at Owens Lake, California (Benson *et al*. 1997), in the Gulf of California (Keigwin and Jones 1990), at Black Mountain Lake and Sky Pond in Colorado (Menounos and Reasoner 1997; Reasoner and Jodry 2000), in reactivated moraines in British Columbia (Friele and Clague 2002) and southern California (Owen *et. al*. 2003), in marine cores off British Columbia (Mathewes, Heusser, and Patterson (1993) and in the Sulu Sea (Kudrass *et al.* 1991), in pollen data from lake sediments at Glacier Bay, Alaska (Engstrom, Hansen, and Wright 1990), in pollen data from a core at Jackson Pond, Kentucky (Wilkins *et al*. 1991), possibly in moraines in Wyoming (Gosse *et al*.

1995), in a bog core and lake sediments from Costa Rica (Islebe, Hooghiemstra, and van der Borg 1995; Orvis and Horn 2000), in pollen data from Colombia (van 't Veer Islebe, and Hooghiemstra 2000), Tierra del Fuego (Heusser and Rabassa 1987), and Chile (Moreno 1997), in moraines in Ecuador (Clapperton *et al*. 1997), in ice cap cores in Bolivia (Thompson *et al*. 1998) and possibly in Peru (Thompson *et al*. 1995), in a New Zealand moraine (Denton and Hendy 1994); in sediment deposition rates, geochemistry, and pollen at Lake Van, in Turkey (Landmann *et al*. 1996); in pollen from cores at Lake Albert, Uganda (Beuning, Talbot, and Kelts 1997) and a peat bog in Burundi (as an aridity signal, Bonnefille *et al*. 1995); in ^{18}O ratios of snail shell from South Africa (Abell and Plug 2000), and in diatoms, pollen, magnetic minerals, and geochemistry of cores from Lake Magadi in Kenya (Roberts *et al*. 1993). As evidence continues to accumulate, it begins to look as though the Younger Dryas might be global in extent (Rutter *et al*. 2000).

Along with these records, there are others where the Younger Dryas is seemingly absent (see, for example, Ashworth and Hoganson 1993; Thunell and Miao 1996; Singer, Shulmeister, and McLea 1998). In some cases, this may be due just to inadequate dating or a sampling resolution that is too coarse, but in others it may reflect a genuine absence of climatic reversal. Elias (1994) finds little or no evidence for it in the North American insect data. Linsley (1996) finds a Younger Dryas-age ^{18}O signal in marine cores from the Sulu Sea, but interprets it as simply a record of global meltwater input, rather than local sea surface temperature. We do not yet know enough about the geographic distribution of the Younger Dryas climatic signal to discern whether its seemingly mosaic pattern is genuine, or an artifact of inadequate sampling. In science, it is often the case that the view is obscured until someone troubles to wipe the windowpane.

One of the most intriguing records comes from the Great Basin, where an extensive series of radiocarbon-dated "black mats" provides a past record of spring discharge and cienega formation. This interval begins at about 11,800 RCYBP and extends well into the Holocene, but the major peak in spring activity clearly coincides with the Younger Dryas (Quade *et al.* 1998:Fig. 5).

In any case, the farflung Younger Dryas records that are known now should indicate that this climatic episode is potentially recognizable anywhere in the world, including Texas. If it has left an imprint in Costa Rica at 2310 meters, perhaps it also could have left an imprint in Texas at 23 meters. Later in this chapter I will examine paleoenvironmental records from the Guadalupe-San Antonio river basins, looking for any evidence of a Younger Dryas climatic signal.

Preboreal and Boreal events

There are a few other minor climatic events following the Younger Dryas, about which even less is known. In the western Great Lakes area, the Marquette ice advance occurs at about 10,000 RCYBP or a little later (Pregitzer *et al*. 2000:46). Anderson, Mullins, and Ito (1997) recognize a regional cold interval at Seneca Lake, New York, which they believe dates to about 10,100-8200 RCYBP, although radiocarbon control is sparse. Kaufman and others (1993) document an ice-stream advance at the mouth of the Hudson Strait at 9900-9600 uncal BP. This seems to reflect mainly the instability of the rapidly melting Laurentide ice sheet and apparently has only regional climatic significance, but in northern Europe and Iceland at about the same time, a regional cold episode known as the *Preboreal Oscillation* has been recognized in pollen and other records, roughly dating 9800-9700 RCYBP uncal (Björck *et al*. 1997; Hammerlund *et al*. 1999:26; Mullins 1998), and attributed to drainage of glacial Lake Agassiz into the Arctic

(Fisher, Smith, and Andrews 2002, who date its inception at 9900 RCYBP and its duration at 150-250 years). Possibly related is the Disko glacial readvance on Disko Island, along the western coast of Greenland, at 9300 RCYBP uncal (Ingolfsson *et al*. 1990). Another 200-year cooling event has been detected in the Northern Hemisphere at about 9100 RCYBP (10,300 cal BP; Björck *et al.* 2001). Slightly later at 8900-8400 uncal BP is another Laurentide ice advance (Kerwin 1996; see also Hu *et al*. 1999), perhaps coeval with the main Mattawa highstand of Lake Huron, at 8900-8100 uncal BP (Rea *et al*. 1994). The best-known of these readvances is the Cochrane advance (8400-7800 BP), which occurred throughout the Canadian Arctic, Hudson Bay, and the James Bay Lowlands (Dawson 1992:100) and possibly even in Washington State (Thomas, Easterbrook, and Clark 2000). Beget (1983) drew attention to various worldwide glacier or icecap readvances radiocarbon dated between 8500-7500 uncal BP. A cold episode at about 9000-8800 cal BP (roughly 8145-8020 uncal BP) has also been recognized in western Europe (Magny 1995).

Even later is a cool episode ("Holocene Event 5," or more commonly just the "8200 BP event") that shows up at about 8200 cal BP (roughly 7457 RCYBP uncal) in the GISP2 ice core (Alley *et al*. 1997; Johnsen *et al.* 2001) and at many other global locations, such as Lake Ammersee, Germany (von Grafenstein *et al*. 1998,), Soppensee and Schleinsee in Switzerland (Tinner and Lotter 2001), at 7440 RCYBP uncal in a marine core from the North Sea and German oak tree rings (Klitgaard-Kristensen *et al*. 1998), in Irish speleothems (Baldini, McDermott, and Fairchild 2002), British land snails (Rousseau, Preece, and Limondin-Lozouet 1998), in isotopes of archeological animal bone from South Africa (Smith, Lee-Thorp, and Sealy 2002), possibly in ice cores from Mount Kilimanjaro (Thompson *et al*. 2002), in various proxies from Taylor Lake, Nova

Scotia (Spooner, Douglas, and Terrusi 2002), Elk Lake, Minnesota (Dean, Forester, and Bradbury 2002), and in the ^{18}O record from Crawford Lake, near Ontario (Yu and Eicher 1998). This cold event is about half as intense as the Younger Dryas, but much shorter-lived (possibly less than 40 years), and has been attributed to the final collapse of the Hudson Bay remnant of the Laurentide Ice Sheet and glacial lake drainage through the Hudson Strait, beginning about 8450 cal BP (Andrews *et al*. 1999; Barber *et al*. 1999; Shuman *et al*. 2002; Clarke *et al*. 2003). It may be hemispheric or even global in extent, but is probably too recent to appear anywhere in the bench deposits at Berger Bluff (for comparison, the timing falls within the Circleville Phase of the Central Texas archeological chronology). There is also, according to Stager and Mayewski (1997), widespread evidence of climatic reorganization at roughly 7460-7015 uncal BP.

These are just a few examples of possible climatic events on a smaller scale at the beginning of the Holocene. Many more examples could be found in the literature, but the difficulties of defining these in time and space are even more pronounced than for the Younger Dryas. Because of the insolation maximum, rapid melting of continental ice sheets and alpine ice caps was the order of the day in the early Holocene, leading to ice sheet instability and ice surging which is difficult to discriminate from episodes of significant global climate change. There are many other kinds of events (for example, isotope discontinuities in soils, discontinuities in pollen and faunal assemblages, and depositional discontinuities in alluvial settings) that can be recognized in the North American early Holocene, especially around 8500 uncal BP. Some of these will be discussed elsewhere.

THE GULF OF MEXICO: SEA LEVEL, MELTWATER, AND TEMPERATURE HISTORY

Sea level during deglaciation

At its present level, the Gulf of Mexico lies about 49 km to the southeast of Berger Bluff at the head of Mission Lake, or 82 km away at the Matagorda Island beach, depending on how one chooses to measure it. At the peak of the Wisconsinan glaciation, sea level in the Caribbean (and presumably in the Gulf as well) stood some 121 m below its present level (Fairbanks 1989:639) and an additional 88 km to the southeast of the present Matagorda Island shoreline (Berryhill 1981a, b).

There are three reasons why Quaternary sea level is relevant to paleoenvironmental studies at Berger Bluff:

1) By Full Glacial time, Texas rivers had extended their channels Gulfward and far to the south across the emergent continental shelf. This affected stream gradients, an effect that gradually diminished as sea level rose again in the Late Glacial period. Whether altered gradients had any effect on stream deposition is a question I will address later.

2) Some rivers that today are independent drainage systems heading farther to the west in widely varying climatic regions of the state were, in the late Pleistocene and early Holocene, linked together as parts of unified drainage systems. Fluvial behavior in one part of the system may have influenced other parts.

3) The open Gulf, with its maritime climatic influence, was twice as far away then as it is now, and this may have had minor effects on local climate, animal ranges, and human behavior.

How much lower was the Gulf, then, and how much farther away? The most important events (summarized in Fig. 2.0) are described by Richard Fairbanks this way:

> Between 17,100 and 12,500 yr BP, the sea level increased by 20 m....This first phase of deglaciation was terminated by an exceedingly rapid sea level rise of 24 m in less than 1,000 radiocarbon years, termed melt-water pulse IA (mwp-IA). Melt-water pulse IA (12,000 yr BP) corresponds to the latter part of Termination Ia (14,500-11,500 yr BP) as defined in deep-sea $\delta\ ^{18}O$ records....Melt-water pulse IA and Termination Ia overlap to some extent, but cannot be synonymous. The rate of sea level rise was at a minimum at 11,000 yr BP, marking the beginning of the Younger Dryas chronozone, and remained low until 10,500 yr BP. The last half of the Younger Dryas chronozone (10,500-10,000 yr BP) is marked by increasing rates of sea level change, culminating in melt-water pulse IB (mwp-IB) centred at 9,500 yr BP. During mwp-IB, which closely corresponds to Termination Ib in deep-sea terminology, the sea level rose ~28 m, similar to the sea level rise associated with mwp-IA (Fairbanks 1989:639).

As sea level in the Gulf rose in estuarine areas, high-biomass marshes perhaps were first created and then drowned by the rising water [although Saucier (1994a:248) suggests saltwater invasion was too rapid to allow biologically productive ecosystems to develop]. A detailed study by Nelson and Bray (1970) of the drowned Sabine River valley did not suggest peat beds were very extensive. Cores drilled through the chenier plain in southeast Texas, however, show the highest concentration of organic matter immediately above the Pleistocene-Holocene boundary (Stewart, Martin, and Lagoe 1996:Fig. 4.

There are many worldwide radiometric data sets available for tracking deglacial sea level rise. There are four that seem most relevant to the Gulf:

1) A composite set of radiocarbon assays on samples recovered from the Gulf itself (Table 2.1). This set of assays (in uncalibrated radiocarbon years) is near the area of concern, and is from a tectonically stable area. The upper Gulf coast has experienced limited subsidence since the Late Glacial, but the central coast is quite stable. Unfortunately, the available assays are on a heterogeneous collection of marine shell, peat, undifferentiated "organics" or "plant" matter, driftwood, and sediment organics. Many of these assays were run decades ago by various oil companies, with lab procedures that do not adhere to modern radiocarbon lab standards. Shore, Bartley and Harkness (1995) have found discrepancies of as much as 1210 years between the humin and humic acid fractions of peat. In most cases, there is no clear documentation of how deep below the water surface the biota are thought to have occurred; in fact, some samples, such as peat, may have accumulated subaerially. There is also a deficit of samples from the 10,000-12,000 RCYBP deglacial phase (Fig. 2.3). Pinter and Gardner (1989) advocate curve-fitting as a method for estimating sea level rise. I have used a curve-fitting program (Tablecurve), but the estimation procedure is simpler than that advocated by Pinter and Gardner. A curve can be fitted to these assays, but there is a wide spread of points about the line. Three anomalous assays and one with a very large standard error were omitted from this data set.

Table 2.1. Radiocarbon Assays of Gulf of Mexico Samples Relevant to Sea Level at 8500-11,000 RCYBP.

Sample	Depth (meters)	Material dated	Date (RCYBP uncal)	
J-201	11.9	shell	8030±220	1
15	16.	shell	8220±293	3
J-207	16.5	shell	8680±270	1
O-1771	16.5	wood, peat	9250±210	7
SP6-1-B#3	17.7	peat	8510±95	5
HI49-3-D#2	17.7	clay	8620±115	5
SP3-1-D1#1	17.7	wood	8800±95	5
SP6-2-E#4	17.7	peat	8840±140	5
HI49-3-E#1	18.6	clay	8935±95	5
EE-16-1A	18.8	shell	8080±100	6
67	18.9-20.3	shell	8265±325	3
SP6-3-A#3	19.2	clay	8585±95	5
99	19.1-20.3	peat	8880±350	3
100	19.1-20.3	wood	8660±230	3
O-228	19.9	shell	8150±180	7
16	20.1	shell	9265±280	3
SP3-1-F#1	20.7	peat	8995±95	5
HI49-2-B#3	20.7	clay	9165±130	5
Tx-8404	20.8	wood	8970±170	8
SP9-4-C#10	21.0	peat	9045±95	5
SP6-2-I#1	21.3	peat	8920±95	5
HI49-2-B#5	21.9	clay	8300±185	5
SP18-2-B#4	21.9	clay	8420±105	5
L-1256	22.25	shell	8700±200	7
78	22.1-22.6	peat	9370±300	3
Tx-1806	22.5	plant	8300±180	4
Tx-1805	22.8-24.3	wood, plant	9580±760	4
SP18-2-B#6	23.5	peat	10,145±285	5
Tx-1980	25.8	plant	9430±100	4
J-482b	26.5	shell	8740±260	1
XS383	27.4	organics	9800±350	2
O-73	29.0	shell	8800±180	7
J-715	30.5	shell	9530±270	1
F-25-1A	34.0	shell	9480±100	6
O-1894	35.0	wood, peat	10,525±215	7
O-353	35.2	shell	8400±150	7
43	35.7	peat	10,207±374	3
J-371	36.6	shell	10,000±400	1
L-291X	42.7	peat	10,700±150	7
O-45	51.7	shell	10,700±220	7
J-403	55.5	shell	11,900±340	1
L-291G	65.5	shell	11,050±300	7

1. Curray (1960:Table II), open Gulf.
2. Shepard (1956:Fig. 2), San Antonio Bay.
3. Nelson and Bray (1970:Appendix), Sabine Pass-High Island area.

(footnotes continued on following page)

(footnotes continued from previous page)
4. Byrne (1975:Appendix 3); Valastro, Davis, and Varela (1977), Lavaca Bay
5. Pearson et al. (1986:Table D-1), Sabine Pass area.
6. Shideler (1986:Table 2), Corpus Christi area.
7. Frazier (1974:Table 1), mostly Mississippi delta.
8. Robert A. Morton, personal communication, 2000.

These assays are all uncalibrated, and insofar as can be determined from the literature, no marine reservoir correction is applied. Assays with very large standard errors are omitted.

Also problematical is the question of what kind of marine reservoir correction to apply to these assays. Assays of Gulf seawater done in 1962 produced these ages (Hood 1963:Table IG):

3 m	-83 yr
600 m	702 yr
1000 m	764 yr
3400 m	519 yr

These are presumably all contaminated with modern anthropogenic (nuclear bomb testing) radiocarbon, so they are of little use in estimating a reservoir correction for the Gulf.

The extensive meltwater in the Late Glacial Gulf was presumably radiocarbon-depleted, but rapid drowning of organic-rich marsh and grassland habitats might well have offset this effect. In addition, as we have already seen, marine reservoir ages in the Atlantic and Pacific are known to have varied by several centuries at the beginning of this period. Shells from estuarine areas of rivers draining the Texas Cretaceous may also have a partial hard-water effect built into the age. Fitting a curve to the assays with no marine reservoir correction (Fig. 2.3) gave an r^2 value of 0.79 (standard error = 5.54), while fitting a curve with a 400-year correction (not illustrated; applied to shell samples only)

actually increased the spread of points somewhat and gave an r^2 value of 0.69 (standard error = 6.67), suggesting that no reservoir correction may be appropriate for these samples. If these assays had been calibrated, the marine reservoir correction would have been selected as part of the calibration procedure (and the 5730-year halflife used, as well), but instead, only the raw assays (and the Libby, or 5568-year halflife) are used.

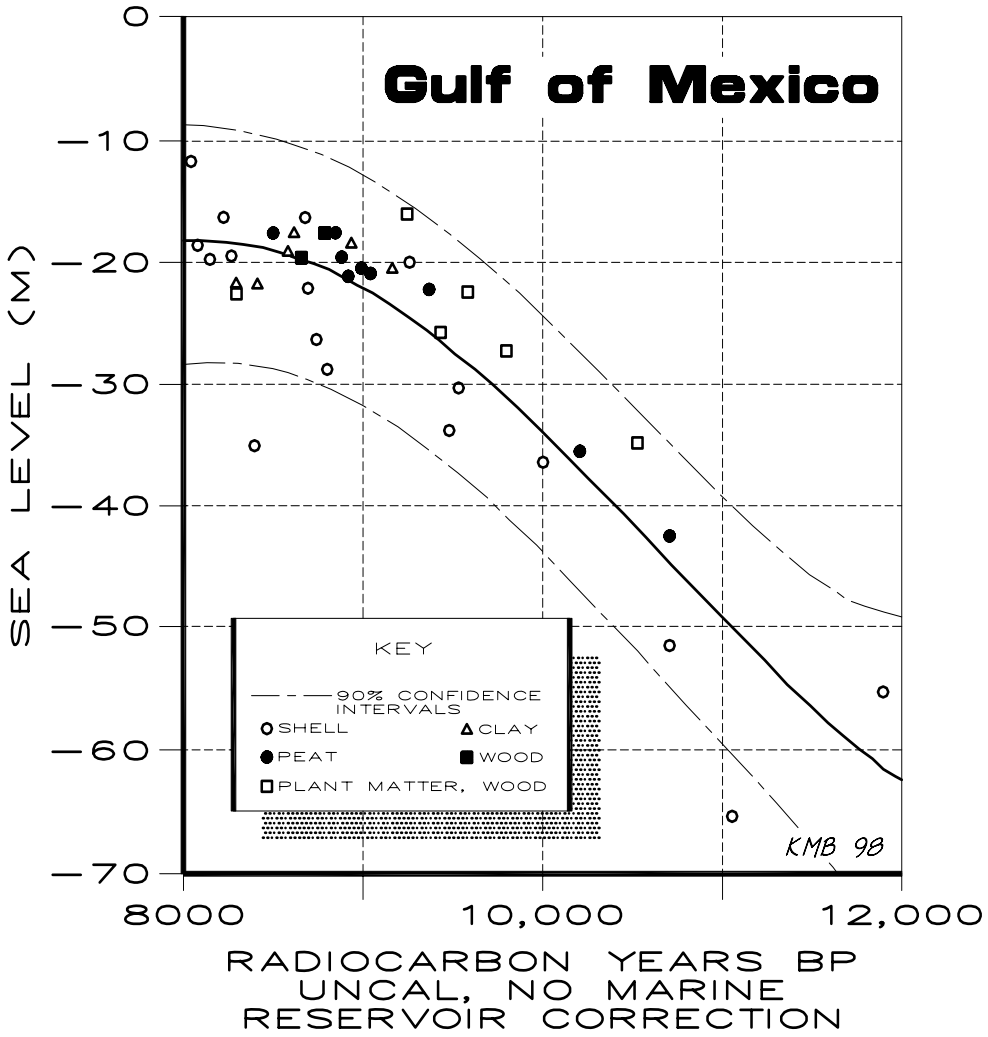


Figure 2.3. Sea Level Estimated from Gulf of Mexico Radiocarbon Assays. Based on assays in Table 2.1, with no marine reservoir correction and no calibration; 90% confidence intervals for curve fit are also shown.

Ricklis and Blum (1997:299) also recommend a +400-year correction for fractionation in shell which, if applied, cancels out the -400-year marine reservoir correction in any case.

2) The second data set is a relatively small group of radiocarbon-dated samples of corals (*Acropora palmata*, which usually grows in the upper five meters of the sea), drilled from raised coral reefs in Barbados. This is a composite set of 15 assays that combines some listed in Fairbanks (1989) with some from Bard and others (1990). The data set has been corrected for tectonic uplift (34 cm per thousand years) and incorporates an invariant 400-year marine reservoir correction. This data set (Fig. 2.4) has a much tighter spread of points than the Gulf data, and it also shows much lower sea level at any given point. The r^2 value for the fitted curve is 0.98 (standard error = 2.81).

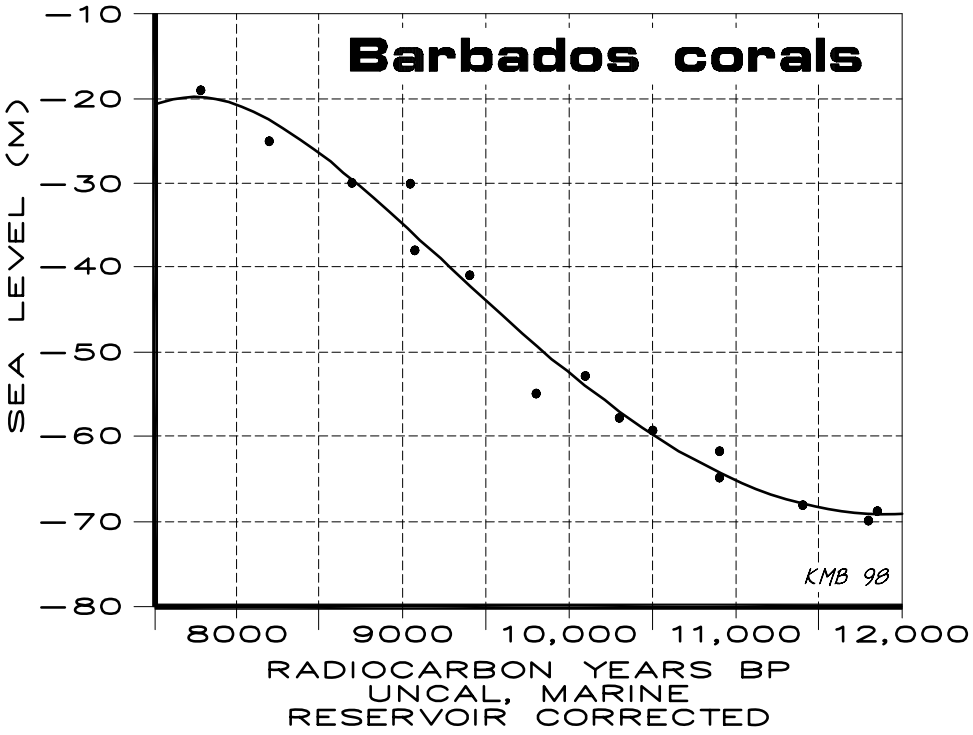


Figure 2.4. Sea Level Estimated from Barbados Corals. This is a composite of radiocarbon-dated *Acropora palmata* samples; data from Fairbanks (1989:Fig. 1) and Bard and others (1990:Table 1). No correction for growth depth range.

3) A set of 29 radiocarbon-dated samples of corals (various genera) from raised coral reefs at the Huon Peninsula in Papua New Guinea (Chappell and Polach 1991). This reef has a faster uplift rate and heterogeneous composition, but the spread of points about the fitted curve (Fig. 2.5) is quite tight, the r^2 value is 0.98, and this solution has a smaller standard error (2.29). It agrees well with the Barbados coral data, showing sea levels perhaps a couple of meters higher at any given date. In terms of sample size and consistency, this is clearly a better data set, even though it is removed halfway around the world from our area of concern. In order to fit the curve shown in Fig. 2.5, I first converted the depths given by Chappell and Polach (1991:Table 1) from depths below coretop to depths below sea level using their uplift correction model:

$$\text{depth below sea level} = (8\text{-coretop depth})-((.001*\text{age})*1.9)$$

where 8 represents the present 8-meter crest of the reef and 1.9 represents the 1.9 meter-per-millennium uplift rate; depths are in meters.

The polynomial curves fitted to the Gulf of Mexico and Huon Peninsula data sets (Figs. 2.3, 2.5) take the form

$$\text{depth in meters} = a + b(\text{age}) + c(\text{age})^2 + d/(\text{age}) + e/(\text{age})^2$$

where a, b, c, d, and e are constants unique to each data set, and *age* is uncalibrated radiocarbon years BP.

The polynomial curve fitted to the Barbados coral data is slightly different:

$$\text{depth in meters} = a + b/\ln(\text{age}) + c/\sqrt{\text{age}} + d/(\text{age})$$

where a, b, c, and d are constants, *ln* is the natural logarithm (base e), *sqrt* is square root, and *age* is uncalibrated radiocarbon years BP.

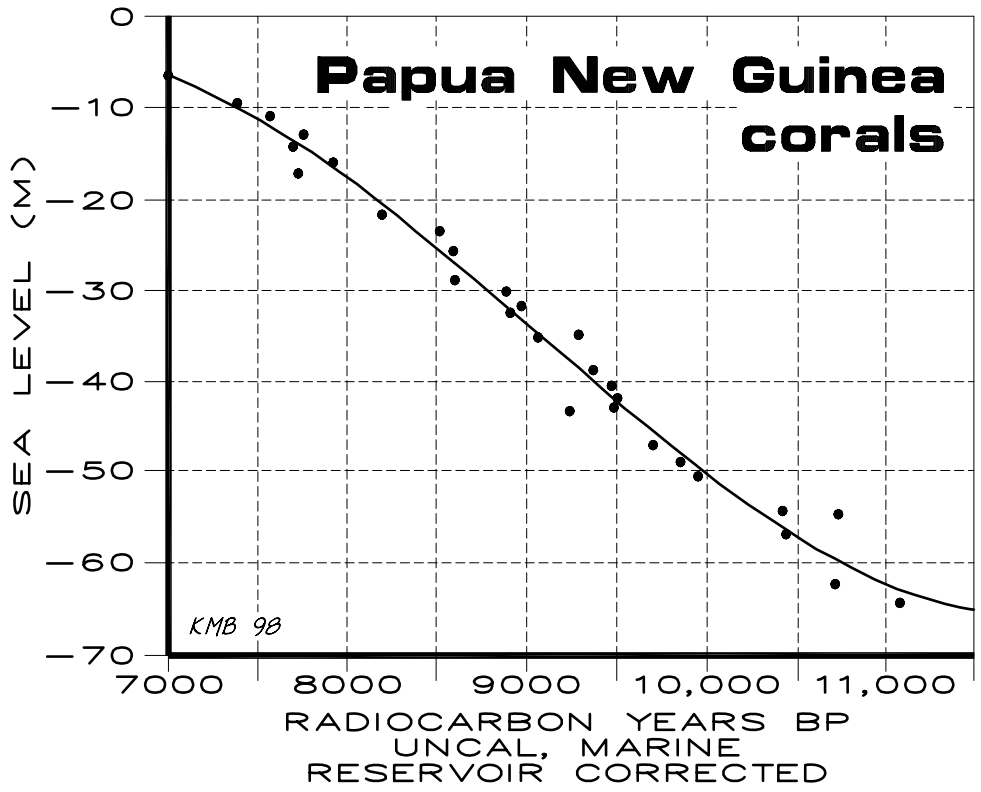


Figure 2.5. Sea Level Estimated from Papua New Guinea Corals. Samples are radiocarbon-dated corals (Chappell and Polach 1991:Table 1) of various genera, corrected for fractionation (and with 400-year marine reservoir correction and uplift correction applied by K. Brown to published data), but not calibrated. No correction for growth depth range.

4) A set of 34 radiocarbon-dated coral samples from Papeete, Tahiti (Bard *et al*. 1996; data downloaded from *Nature* Supplementary Data on the World Wide Web); I used all except the most recent assay, but only the part of the curve before 7000 RCYBP is shown in Fig. 2.6. The r^2 value for the entire curve from 5040 to 11,790 RCYBP. The assays have been corrected for fractionation and for marine reservoir content of -40 ‰. The fitted curve has an r^2 value of 0.99 (standard error = 1.44). Tahiti is a tectonically stable area, so no uplift correction is necessary, and the depths shown are below contemporary sea level. This data set yields a sea level of -74.7 m at about 11,000 RCYBP and about -38.4 m at 8500 RCYBP. These levels are significantly lower than those calculated from the other two data sets (Table 2.2), possibly because their uplift rate models may be somewhat in error.

Table 2.2. Sea Level Estimated by Curve-Fitted Data Sets.

Data set	**Sea level estimates (meters below present sea level)**			
	8500 BP	9000 BP	10,000 BP	11,000 BP
Barbados	-26.55	-34.90	-52.64	-65.32
Huon Peninsula	-25.32	-33.77	-50.34	-62.36
Tahiti	-38.42	-46.48	-62.03	-74.74
Mean:	-30.11	-38.38	-55.00	-67.47

NOTE: Estimates derived by curve-fitting points with known depth and radiocarbon age (see text for details). Barbados and Huon data incorporate uplift corrections. Data sources: Barbados: Fairbanks (1989), Bard *et al.* (1990); Huon Peninsula: Chappell and Polach (1991); Tahiti: Bard *et al.* (1996, data from web site). Dates are uncalibrated radiocarbon years; uranium/thorium age assays were not used for these estimates.

All of these coral data sets have uranium-thorium age estimates as well, which serve to confirm the radiocarbon assays, but I have not used the U/Th estimates, which correspond to calendar years.

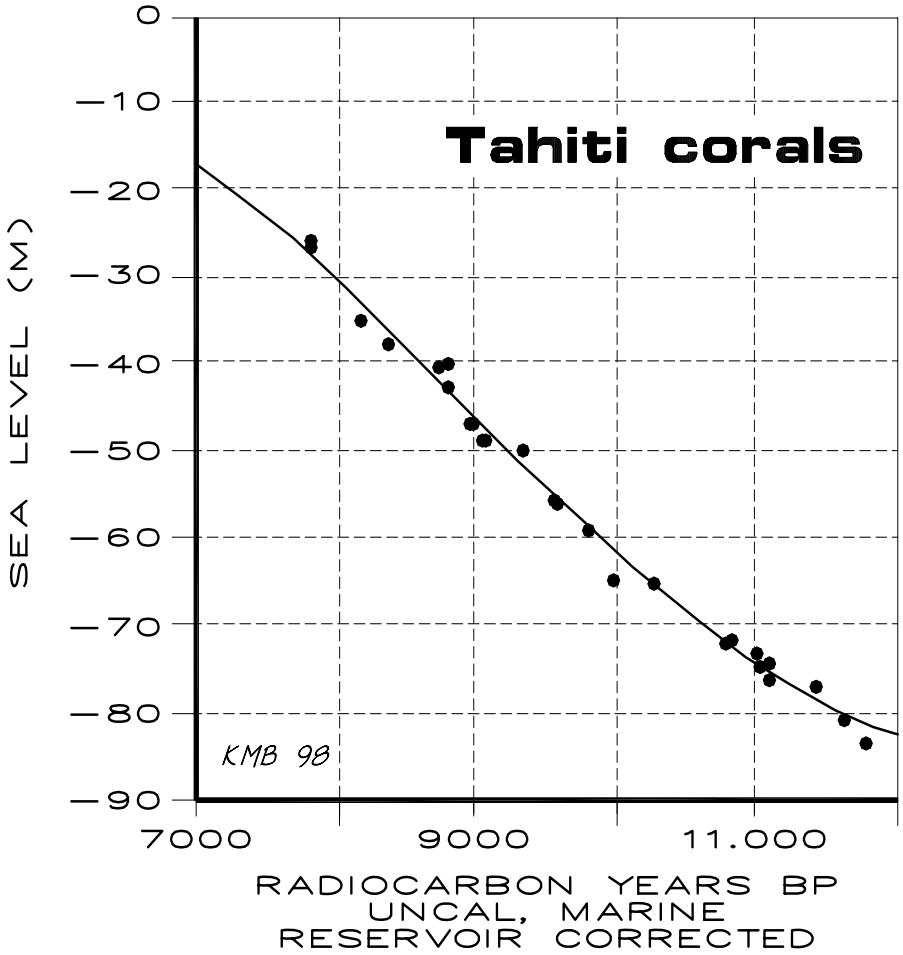


Figure 2.6. Sea Level Estimated from Tahiti Corals. Samples are radiocarbon-dated corals (Bard *et al*. 1996) of various genera, corrected for fractionation and marine reservoir effect. Data derived from *Nature* Supplementary Information downloaded from the World Wide Web; assays more recent than 7000 BP were not used. Depth is below current sea level; no uplift correction required.

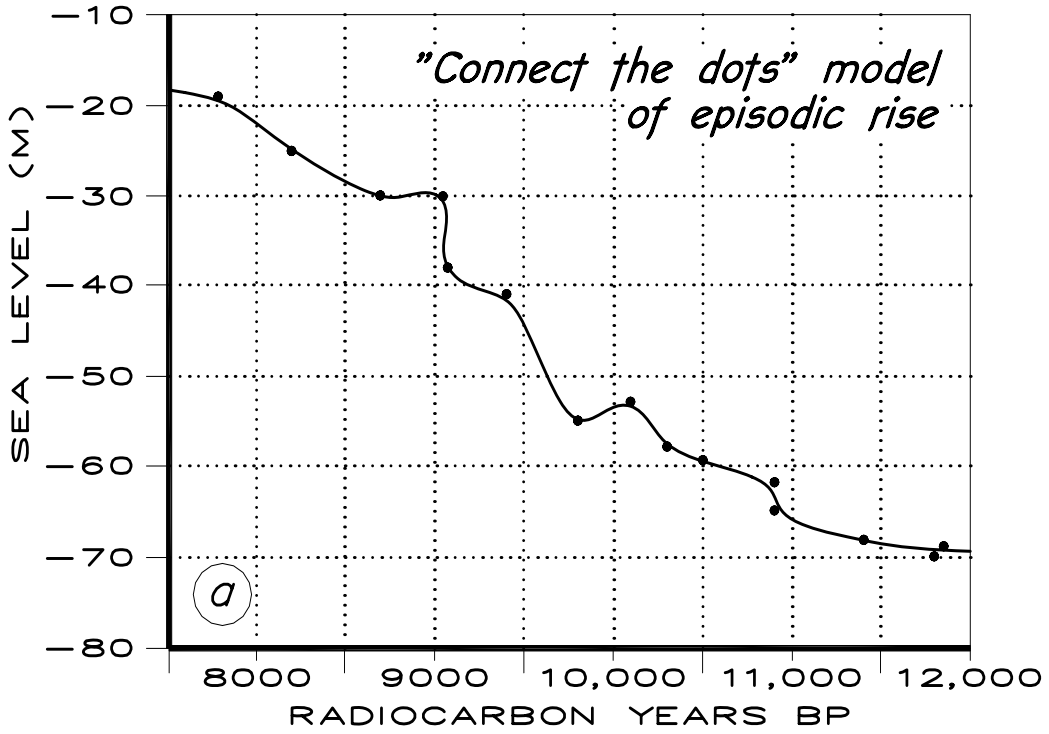
How episodic was sea level rise?

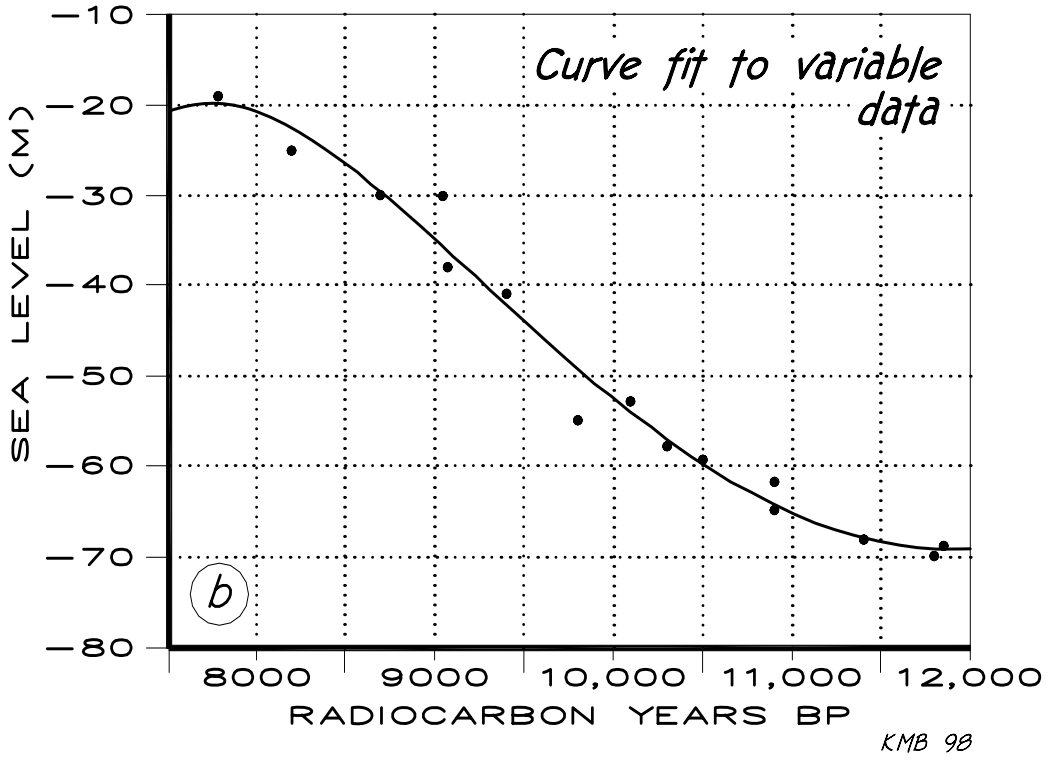
There are several lines of evidence suggesting that sea level has not simply risen monotonically throughout the Late Glacial and Holocene, but has experienced acceleration, stillstands, highstands, and regression, although probably not to the extent suggested in the older literature. Many of the early published sea level reconstructions for

the Gulf, based on rather sparse data, proclaim rather dramatic fluctuations in sea level (Morton and McGowen 1980:Fig. 60,c; Stright 1995:Fig. 7). In large part, this may be the effect of a "connect the dots" model of sea level reconstruction, in which widely scattered and disparate samples are joined to create "highstands" and "lowstands"(Fig.2.7, *A*). Fitting a statistical curve to a cleaner data set like the Huon Peninsula corals, as in Fig. 2.5 or Fig. 2.7, *B*, gives hardly any indication of episodic sea level change. A recent review of coastal archeological sites by Ricklis and Blum (1997) posits two periods of rapid rise later in the Holocene, one after 7000 cal BP and another between 4000-5000 cal BP, based largely on the absence of terrestrial components in these periods.

While it might seem that the postglacial history of abrupt and episodic climate change as presented in Chapter 1 would argue for strongly episodic sea level change, there are impressive lag effects involved in melting of large ice sheets. I attribute most of the variance seen in the Gulf of Mexico samples (Fig. 2.3) not to rapidly oscillating sea level, but to dating errors (large standard errors and uncertainty about marine reservoir ages) and provenience errors (for example, reworked shell, subsidence, turbidity flows, or organic material that might have formed in place well above sea level rather than at sea level).

While the first two coral data sets (Figs. 2.4, 2.5) are in good agreement, the mixed Gulf of Mexico data set (Fig. 2.3) is in agreement only at about 8000 RCYBP; before that, estimates run about 15 meters too high, compared to the Barbados and Huon Peninsula coral data sets, and 25-28 m too high according to the Tahiti data set.


"Connect the dots" model of episodic rise
SEA LEVEL (M)
−10
−20
−30
−40
−50
−60
−70
−80
8000
9000
10,000
11,000
12,000
RADIOCARBON YEARS BP
a


Curve fit to variable data
SEA LEVEL (M)
−10
−20
−30
−40
−50
−60
−70
−80
8000
9000
10,000
11,000
12,000
RADIOCARBON YEARS BP
b
KMB 98

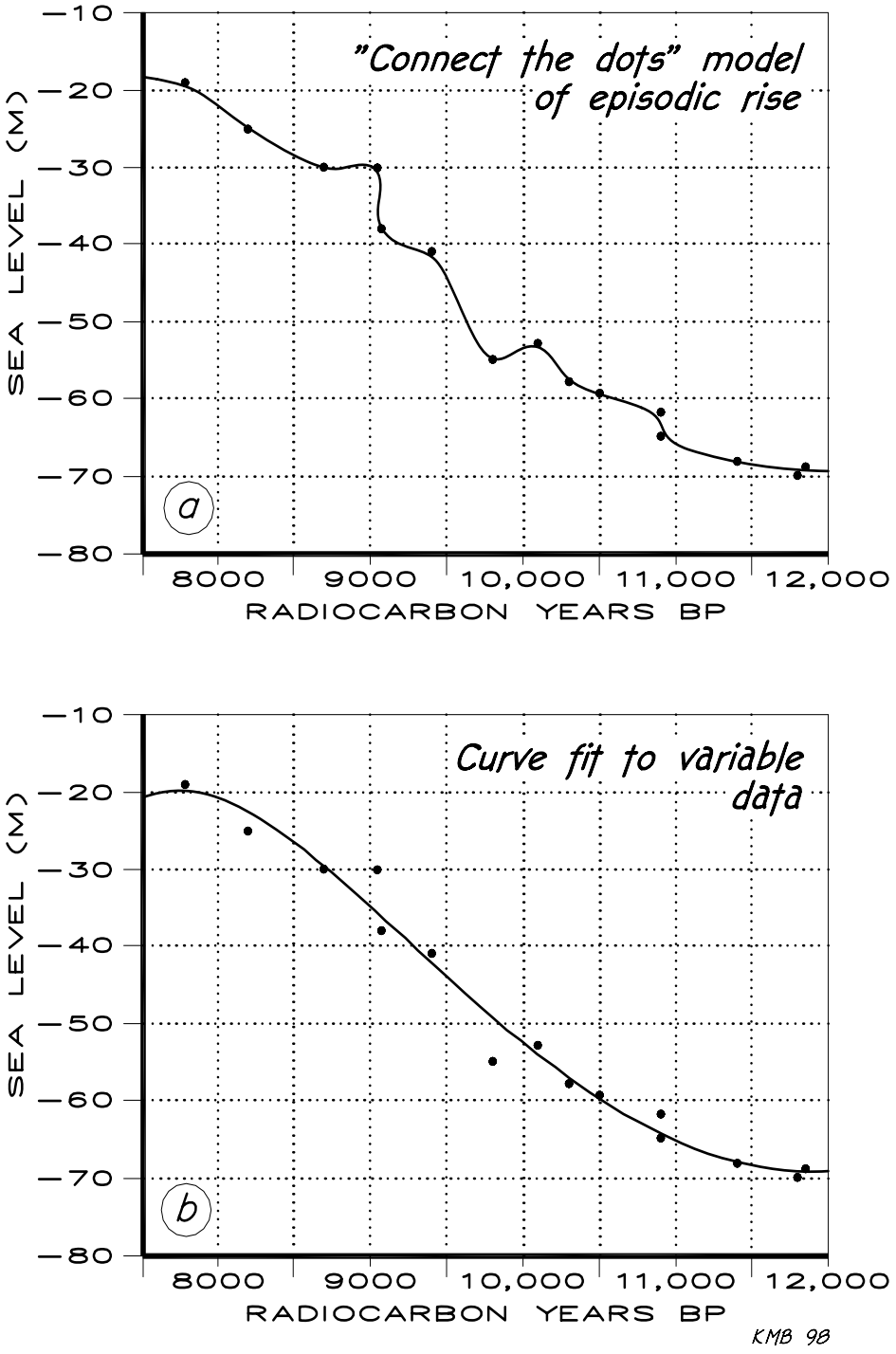


Figure 2.7. *A*, Episodic or "Connect- the- Dots" Model of Sea Level Rise; *B*, Monotonic Model of Sea Level Rise.

A highly critical review by Kidson (1982) of past efforts to compile a global sea level curve concludes that "the acceptance of the concept of *geoidal eustasy* means that eustasy as a world-wide phenomenon... can no longer be regarded as valid....The search for a universal eustatic curve must be regarded as over" (Kidson 1982:131, 144). What he means is that there are regional variations in sea level, to the extent that sea level can actually be higher by several meters in one region than in some adjacent region. Kidson points to variation in datum points, variation in definitions of sea level, varying tidal ranges, errors in choice of dated samples, errors in measuring sample elevation, and errors in dating as reasons for discrepancies between different regional sea level curves — and the discrepancies are sizable (see Kidson 1982:Fig. 1).

Better evidence for episodic sea rise comes from detailed studies of coral reef species composition in the Caribbean-Atlantic area by Blanchon and Shaw (1995), who recognize three periods of accelerated sea level rise. Only two of those occur during the period of concern here. One, designated CRE2, was a rapid 7.5 m rise at about 11,500 cal BP (roughly 10,090 RCYBP), while CRE3 was a 6.5 m rise at about 7600 cal BP (about 6810 RCYBP). Note, however, that the CRE2 rise does not show in Fig. 2.4, and if it corresponds to meltwater pulse IB as defined by Fairbanks (1989), the timing is somewhat different. Evidence for CRE3 has been disputed by Toscano and Lundberg (1998).

Some of the most intriguing evidence for episodic sea level rise can be found in the form of submerged wave-cut notches off the coast of Oahu. The notches were cut during stillstands, then preserved when accelerated rates of sea level rise left them well underwater. Fletcher and Sherman (1995) have identified a series of features at depths of

47-67 m that they identify with the Younger Dryas reduction in rate of rise. Meltwater pulses are indicated by sloping planation surfaces.

Effects of rising sea level on channel gradients

At present, the 23 m vertical drop from the 75 foot contour where it crosses Coleto Creek near Berger Bluff, to sea level in San Antonio Bay extends over an 83 km distance, producing a channel gradient of about 27 centimeters per kilometer; Table 2.3 lists very rough estimates of changing channel gradients during the Late Glacial/Holocene transgression for the combined Coleto Creek-Guadalupe River system. Bathymetric contours for specified time intervals are based on the Huon Peninsula curve shown in Figure 2.5. Actually, although I have anchored all but the first estimate at the 75 foot contour line upstream, at the downstream end the estimates are simply anchored at sea level rather than the channel bottom. Some of these estimates would be much improved if a detailed longitudinal profile could be incorporated, and the actual channel base could be used as the downstream anchor point. Mapping by Wright (1980:Fig. 33) of the Pleistocene Guadalupe River channel, now submerged under San Antonio Bay, shows the channel is over 80 feet (24 m) below present sea level. Unfortunately, comparably detailed mapping Gulfward is lacking. As a result, where I have used the 6 m bathymetric contour off Matagorda Island as the base level estimate for 7000 BP, the computed channel gradient is 0.2261 m/km, which is actually *less* than the present 0.2294 m/km gradient anchored at Grassy Point. In reality, the 6 m contour at 7000 BP would have been found well up into the interior of San Antonio Bay, since Matagorda Island did not exist yet. This illustrates the level of imprecision introduced where detailed channel profiles are lacking. In San Antonio Bay itself, wood fragments buried in Guadalupe River fluvial sediments at about 90 feet (27 m) below current sea level provided a

radiocarbon assay of 9800±350 uncal BP, run by Magnolia Petroleum in the 1950s (Shepard 1956). This assay appears in Table 2.1 and on Fig. 2.3, but is about 23 m higher than sea level estimated with the coral data sets, and may not be a good estimator of sea level position.

Table 2.3. Estimated Channel Gradients, Coleto Creek/Guadalupe River Drainage.

	Channel length along present meandering channel (km)	Gradient (m/km)	Channel length along valley axis (lm)	Gradient (m/km)
Local gradient at Berger Bluff		1.57		
Berger Bluff to present sea level at Traylor Cut	83.16	0.2749		
Berger Bluff to present sea level, head of Hynes Bay			62.56	0.3654
Berger Bluff to end of delta at Grassy Point	99.64	0.2294	67.15	0.3404
Berger Bluff to 120 m bathymetric contour (18,000 RCYBP)	215.14	0.6640	182.65	0.7822
Berger Bluff to 62 m bathymetric contour (11,000 RCYBP)	185.27	0.4580	152.78	0.5554
Berger Bluff to 50 m bathymetric contour (10,000 RCYBP)	176.14	0.4246	143.65	0.5072
Berger Bluff to 25 m bathymetric contour (8500 RCYBP)	151.14	0.3167	118.65	0.4034
Berger Bluff to 6 m bathymetric contour (7000 RCYBP)	127.64	0.2261	95.15	0.3033

NOTE: Measurements along submerged channel axes are based on mapping by Wright (1980:Fig. 33) and Berryhill (1981a, b). Due to lack of knowledge of submerged channel depth, these are minimum estimates of gradient. The actual gradients would have been somewhat steeper, especially for the more recent periods.

Lack of detailed knowledge about the actual (meandering or straight) channel pattern introduces further uncertainty. In Table 2.3, channel distances in the first column are measured along the present meandering channel as far as the head of San Antonio Bay, thence down the submerged channel axis, following mapping by Wright (1980) and Berryhill (1981a, b). The reader should note that the map version published later by Berryhill (1987:Fig. 2-2) indicates a different and much longer path to base level and would probably reduce all of the premodern gradients in Table 2.3 considerably. Distances in the third column are measured down the valley axis for the entire distance, giving an estimate of the steeper maximum gradient that would be obtained if the entire drainage had a "straight" meander pattern. The reader can get some sense of the potential scale of channel patterning by examining the paleogeography of the lower Guadalupe River valley proposed by Weinstein (1992:Fig. 10-1).

Now that some of the deficiencies in Table 2.3 have been identified, the important thing to note is that the gradient estimates steadily diminish from 18,000 uncal BP to 7000 uncal BP, regardless of whether the meandering or valley-axis estimates are used. This suggests that rising sea level had an effect on coastal plain stream gradients, despite the lengthening of the channels that occurred during lowstands.

Over long distances, stream profiles have a concave-upward longitudinal profile (Morton and McGowen 1980:Fig. 3), and local gradients may differ markedly from the overall gradients presented here. At present, the Coleto Creek segment of the drainage has a much steeper gradient (0.50 m/km) than the Guadalupe River segment (0.13 m/km), just as we would expect, since the former is a mixed-load stream and the latter is a

suspended-load stream. Gradients may have been locally heterogeneous. The local creek gradient near the site is even higher (1.57 m/km). Likewise, for the river,

> For example, between Victoria and the river mouth, sinuosity [of the Guadalupe River] changes from 2.24 to 1.03; width/depth ratio decreases from 8.1 to 5.8; and channel gradient decreases from 1.73 ft/mi (0.33 m/km) to near 0 along lower reaches of distributary channels (Morton and McGowen 1980:52).

Dredging of the lower Guadalupe River channel, at least as far as Kemper's Bluff, was begun in 1857 (Rose 1961:26-28) and, except when interrupted by the Civil War, has been continued to the present. Maximum bankfull depth in the delta area is 16 feet (4.9 m; Donaldson, Martin, and Kanes 1970:Table 1). Logjams and debris rafts may have locally altered gradients, and there may have been times when lower Coleto Creek extended a meander belt ridge out onto the Guadalupe River floodplain, if the river was unable to flush it away.

Wright (1980:82-83) makes an important observation about the submerged Nueces River channel — although the depth of the channel base at the continental shelf break is unknown, projecting the part that is known seems to indicate it lies at about 79 m, which is well above the Wisconsinan lowstand of -120 m. Wright suggests this means the river was still downcutting when postglacial sea level began to rise again. In other words, the river was not yet in equilibrium with its base level, even though it had several millennia over which to adjust its gradient. If adjustment to lowered base level was significantly lagged, adjustment to rising base level may have been even more delayed.

Examination of meander patterns on USGS maps gives some idea of the progress of adjustment to postglacial base level. Both the lower Guadalupe River and the lower

part of Coleto Creek (as far upstream as Raisin) snake actively back and forth within wide valleys. If Coleto Creek is followed upstream from its confluence with the river, it can be seen that the creek enters a confined valley at Raisin and remains within it, following a much straighter course, for the duration of its travels through the Goliad Formation, into which it is rather deeply incised. It is not clear whether the previous history of valley entrenchment is the chief control on the channel pattern here, or whether the channel pattern is a reaction to the postglacial history of base level. Ouchi (1985:Fig. 12) attributes increased sinuosity of the Guadalupe River and San Antonio River in this vicinity to bedrock deformation in the Post-Vicksburg flexure zone.

Relatively little is known about the effects of rising base level on stream behavior. A study by Berendsen (1995) of paleochannels of the Rhine over 50 km inland from the present coast of the Netherlands showed that periods of accelerated Holocene sea level rise were marked by episodes of rapid avulsion of the river. This suggests base level control may extend at least this far upriver in flatlying terrain.

Geomorphologists have used experimental scale models of drainage to investigate the effects of different hydrologic variables. In one such study, following artificial base level lowering,

> Incision occurred first at the mouth of the basin, and then progressively upstream, successively rejuvenating tributaries and scouring the alluvium previously deposited in the valley. As erosion progressed upstream, the main channel became a conveyor of upstream sediment in increasing quantities, and the inevitable result was deposition and formation of a braided stream...However, as the tributaries became adjusted to the new baselevels, sediment loads decreased, and a new phase of main-channel erosion occurred (Schumm 1977:75-76).

Schumm refers to this lagged reaction to base level lowering as *complex response* of the drainage system. The implication is that 1) changes in base level may have a wavelike effect that ripples throughout the drainage system, but 2) significant time lags in response may occur. In the Coleto Creek case, it might be relevant to ask whether any of the perceived Holocene changes in stream behavior represent long-delayed responses to Full Glacial base level lowering.

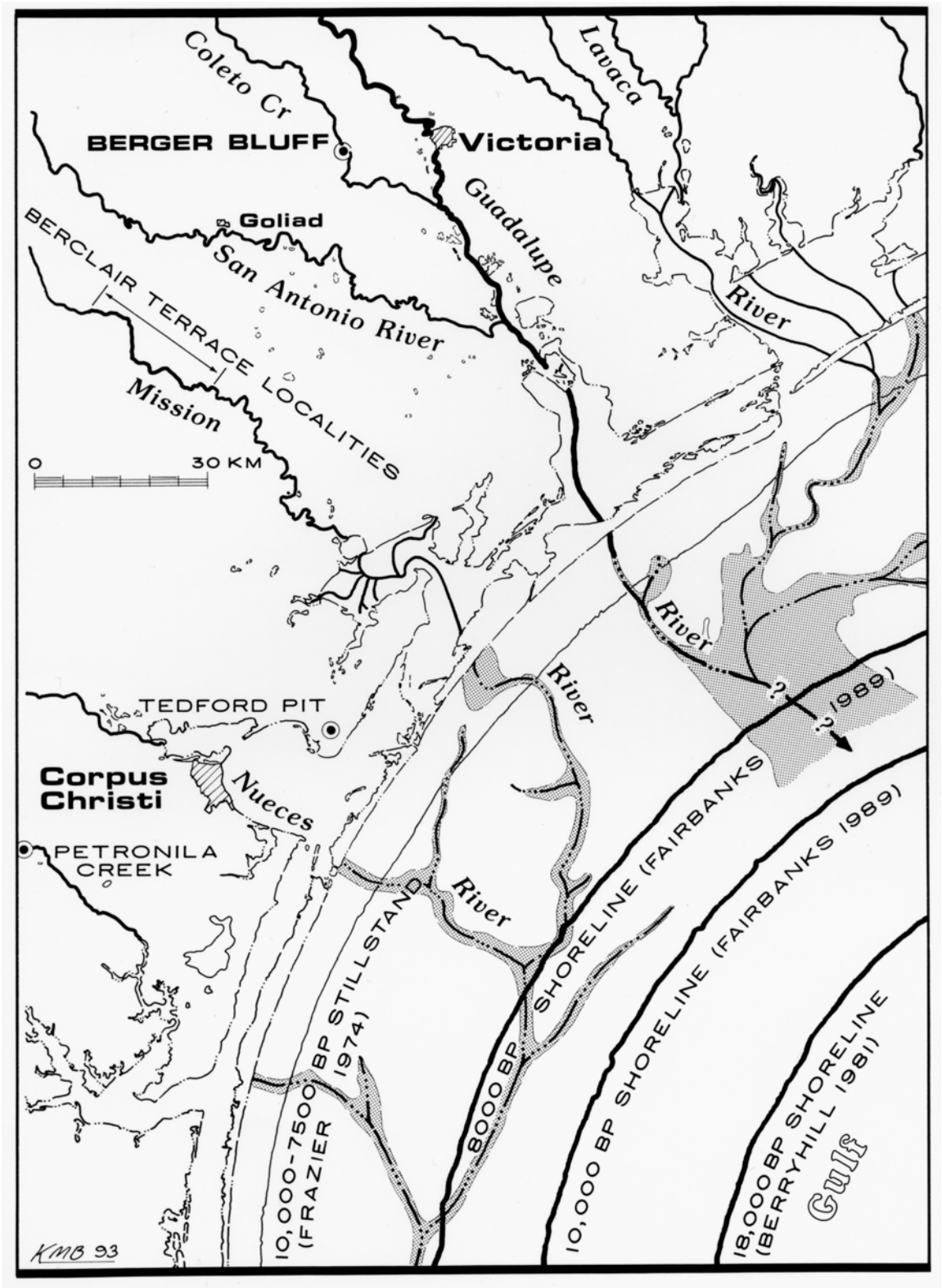
In any case, the gradient history of the Coleto Creek-Guadalupe River drainage is of more than academic interest, because it is significant for understanding the aggradational history of Berger Bluff. In a later chapter I will argue that the creek bed at the site has probably experienced pronounced vertical movement (both up and down) during the Holocene, related both to climate history and perhaps to whatever we can deduce about gradient history.

Changing postglacial basin boundaries

Mapping by Berryhill (1981a, b) indicates that at the nadir of the Wisconsinan lowstand, the Guadalupe/San Antonio river basins were united with the Lavaca/Navidad river basins and the Tres Palacios Creek basin in a single drainage system (Fig. 2.8), and remained so until sea level rose above approximately the 26 m bathymetric contour, somewhat before 8500 RCYBP uncal, and covered the confluence area, which now lies over 27 km offshore. Later mapping by Berryhill (1987:Fig. 2-2) seems to indicate a revised paleogeography, with all of these drainages joining the Mission River, Nueces River, and Los Olmos Creek /Palo Blanco River to form a single unified drainage flowing southward toward the Rio Grande estuary. In other words, the 1987 version seems to indicate all of the streams of the southern and central coast between the Rio

Grande and Brazos River were tributaries to a unified river system. Potential effects of this enlargement on fluvial behavior of Coleto Creek are unknown. The enlarged drainage area encompasses regions that today vary from slightly more humid to much more arid than the Berger Bluff catchment, and may have been likewise in the Pleistocene.

Figure 2.8 *(following page).* Paleogeography of the Central Gulf Coast. Proposed shorelines at 18,000 BP (Berryhill 1981a, b), 10,000 BP, 8000 BP (Fairbanks 1989), and 10,000-7500 BP (Frazier 1974) are shown (all dates are uncalibrated radiocarbon years), as well as submerged paleochannels of the San Antonio/Guadalupe/Lavaca River and Petronila/Nueces/Mission River systems.


Coleto Cr
BERGER BLUFF
Victoria
Lavaca
Guadalupe
River
Goliad
San Antonio River
BERCLAIR TERRACE LOCALITIES
Mission
0
30 KM
River
River
TEDFORD PIT
Corpus Christi
Nueces
PETRONILA CREEK
River
? ? 1989
10,000-7500 BP STILLSTAND (FRAZIER 1974)
8000 BP SHORELINE (FAIRBANKS
10,000 BP SHORELINE (FAIRBANKS 1989)
18,000 BP SHORELINE (BERRYHILL 1981)
Gulf
KMB 93

Gulf of Mexico water temperature history: literature review

Past water temperatures for the Gulf of Mexico have been estimated with 1) transfer functions that compare modern planktonic foraminifera species with known temperature requirements to assemblages found in marine cores, 2) oxygen isotope data from foraminifera in cores, and 3) gas chromatograph analyses of alkenones extracted from sediments in cores. Further information comes from the known history of meltwater influx from the Mississippi River, based on modeling of the Laurentide ice sheet, studies of alluvial deposits in the Mississippi River valley, and studies of percentages of reworked foraminifera. Unfortunately, age control on many of the older (pre-AMS) studies is poor. Many of the older studies are anchored only by a few known points — for example, the core top is assumed to date to the present, and the Pleistocene-Holocene boundary (easily recognized by the Holocene reappearance of the foraminifer *Globorotalia menardii*) is taken as another known point. Points in between are simply dated by interpolation, assuming a constant rate of sedimentation. However, the Pleistocene-Holocene boundary (termed the Y/Z faunal boundary or the isotope stage 1/2 boundary) which is normally taken as 10,000 RCYBP in terrestrial records, has been variously taken as 13,000 or 12,000 or 11,000 RCYBP in marine core research. In records that have been *orbitally tuned* (adjusted to the scale of insolation cycles), other ages may be assigned.

Brunner (1982) studied 17 marine cores from the Gulf, looking specifically at the time interval she estimated as 18,000 BP uncal, based on extrapolation from the Y/Z boundary (estimated at 11,000 BP uncal based on radiocarbon dating in the Caribbean). The cores are undated, however. She used transfer functions to estimate paleotemperature and paleosalinity from modern foraminifera assemblages. She estimates that at the glacial

maximum, Gulf waters were 1° to 2° C cooler and 0.3 ‰ less saline in winter than at present, and 1° C cooler and 0.6 ‰ more saline in summer than at present (the present average summer temperature is about 29° C, and along the western continental shelf, the winter temperature ranges from about 18° to 21° C). Estimated summer temperatures in the western Gulf, offshore from the Texas central coast, ranged from about 26° C to 26.8° C (Brunner 1982:Fig. 3). One core (K147) collected in the Gulf east of Port Isabel suggests a summer temperature 3.3° C cooler than at present (Brunner and Cooley 1976:Fig. 3). The salinity differences suggest that in winter, the Mexico Basin was fresher than at present because the climate was more mesic, but in summer evaporation rates rose, and the climate was more arid.

Several studies of cores from the Gulf have examined oxygen isotope history. The earliest work by Emiliani treated the isotope curves as indicators chiefly of temperature history. Since then, it has become clear that the isotope content of microfossils is controlled both by the ambient seawater temperature and by the isotopic composition of the water itself, which is heavily influenced by the rate of meltwater influx. During glacial meltwater episodes, meltwaters that are highly depleted in ^{18}O (typically about -35‰) flowed into the Gulf and mixed with surface seawater slightly enriched in ^{18}O (about +1.7‰) by evaporation to yield large negative ^{18}O signals recorded in foraminifer shell chemistry. Current opinion holds that the rate of meltwater influx accounts for around 70-75% of the isotope signal (Dawson 1992:9-10). Unfortunately, it is difficult to separate the temperature and meltwater components of the isotopic signal.

Leventer, Williams, and Kennett (1982) studied oxygen isotopes in foraminifera from a piston core (EN32-PC6) extracted from the Orca Basin (see Fig. 2.9, *D* for

location). This is a fairly detailed record (samples every 5 cm through the meltwater interval, and every 10 cm elsewhere), but initial attempts at age control were poor, based on a single carbonate radiocarbon date at 3915 RCYBP and on the Y/Z biostratigraphic boundary, again assumed to date 11,000 BP. The age of the bottom part of the core is simply extrapolated. Based on these age estimates, meltwater discharge first appears at 16,500 RCYBP uncal, with a major pulse from 14,900-11,600 RCYBP uncal, with a magnitude of 2.6 ‰. After the isotope minimum at 11,600 RCYBP, the curve begins to rise again toward negative values that are more or less typical of the Holocene (Leventer, Williams, and Kennett 1982:Fig. 3). However, the age estimates are apparently too old.

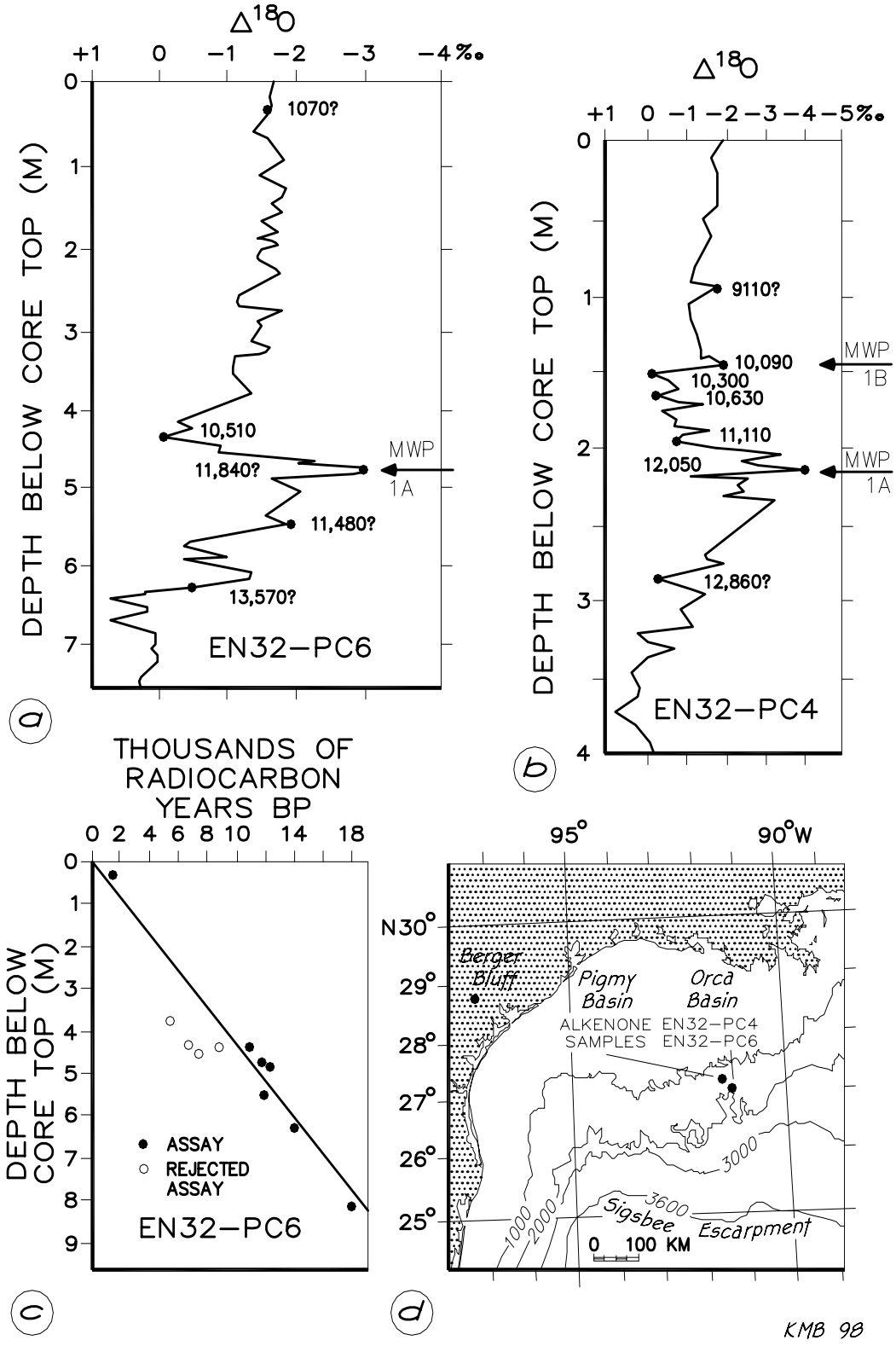
Broecker and others (1988:Table 1) published 10 AMS assays on individual foraminifera from this core and discovered a major age discontinuity from about 7000-11,000 RCYBP uncal. Their initial interpretation was that about 4000 years' worth of sediment is missing from the section for some reason. To check the discrepancy, an additional AMS assay at 436-437 cm (10,910±160 RCYBP uncal) was obtained (Broecker *et al.* 1990:Table 5). The new assay suggested that perhaps no sediment was missing, but instead four of the previous assays were erroneous for some unknown reason (see Aharon 2003:page 3-8). The age-depth relationship for this core is shown in Fig. 2.9, *C*, where the rejected assays are shown as open circles (no marine reservoir correction is applied to this scattergram).

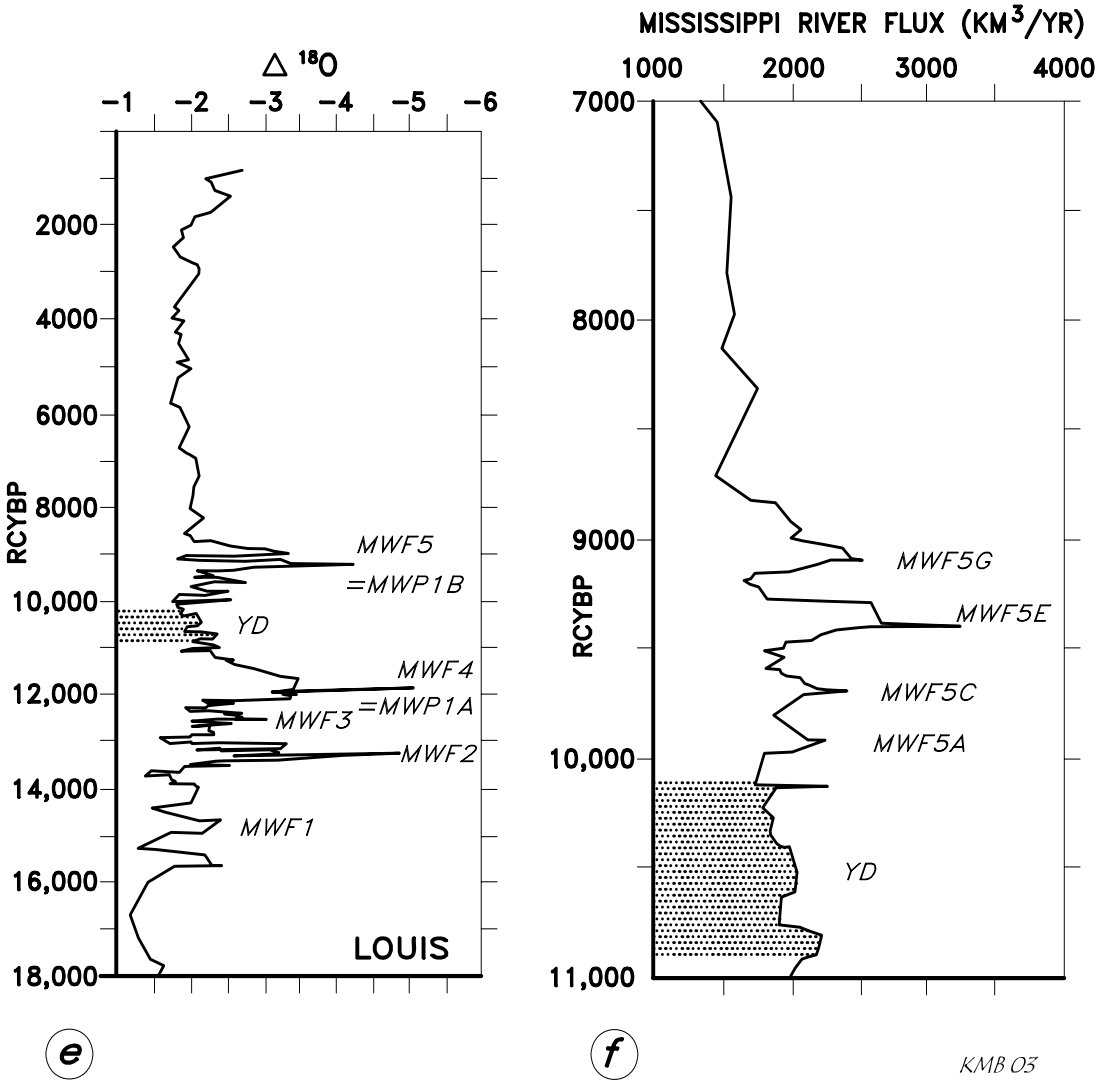
The oxygen isotope curve shown in Fig. 2.9, *A* is the same as that published by Leventer, Williams and Kennett (1982:Fig. 1) and likewise by Broecker *et al.* (1990:Fig. 7), but with the most recent (and correct) dating. The assays listed in Fig. 2.9, *A* and *B* come from the published date lists (with a 400-year marine reservoir correction applied)

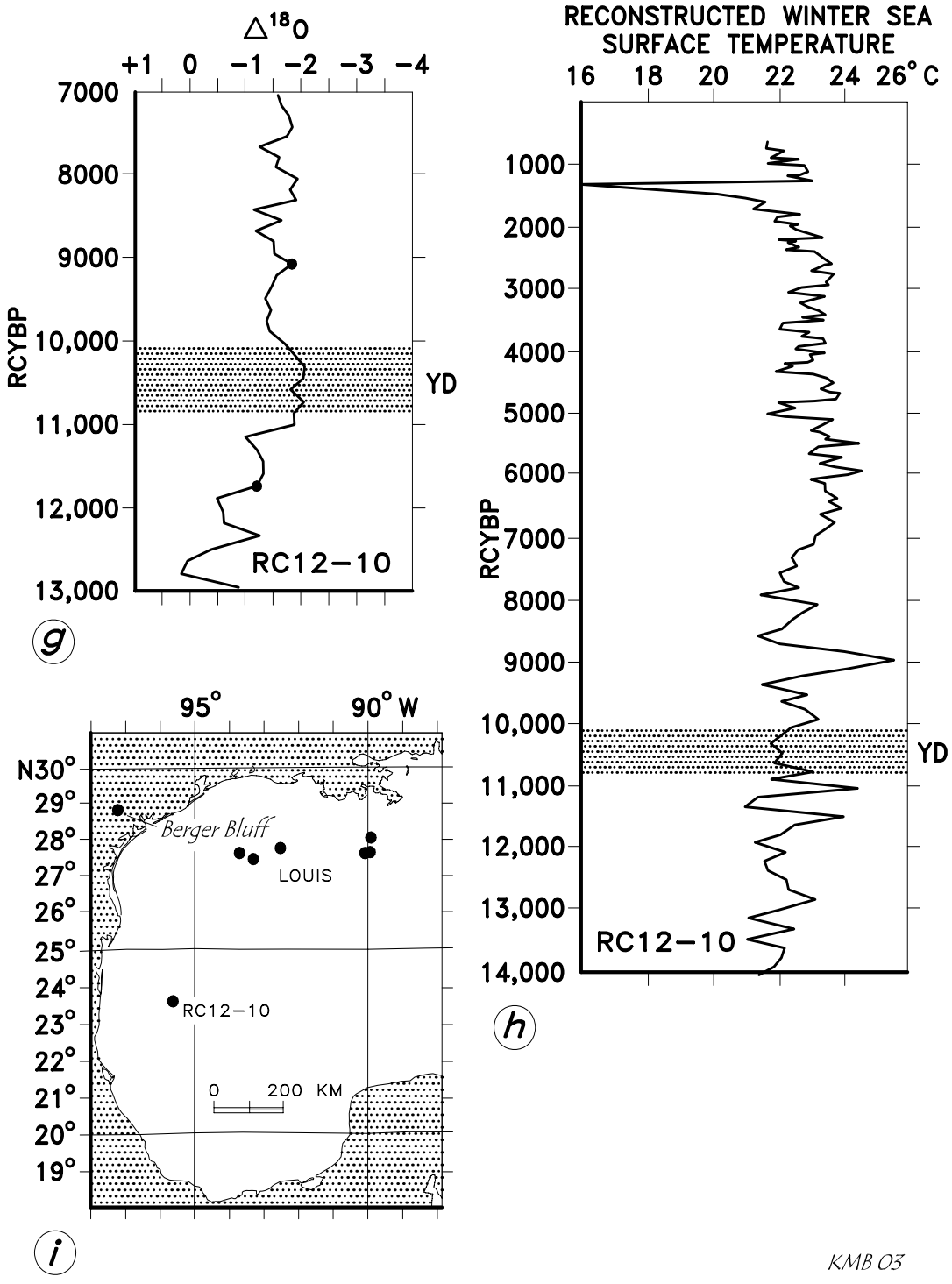
and the illustration is patterned after Broecker *et al*. (1990:Fig. 7), but the dates I show here differ from those in the original figure (discrepant dates are indicated by a question mark). There is no apparent reason for the discrepancy, but since the values in Fig. 2.9 are derived directly from the published date lists, I presume they are the most accurate radiocarbon estimates available. Some of the assays listed in Broecker *et al*. (1990:Table 5) are apparently new assays from samples assayed in Broecker *et al*. (1989:Table 2). The isotope curves from both cores clearly show the presence of meltwater peak IA at about 11,800-12,000 RCYBP uncal, followed by a lack of meltwater during the Younger Dryas. Core EN32-PC4 (Fig. 2.9, *B*) suggests a secondary meltwater peak (IB) at about 10,090 RCYBP uncal, but EN32-PC6 (Fig. 2.9, *A*) just shows stabilization at Holocene values, rather than a discernible peak.

There are a few additional earlier studies that are worth reviewing, even though they predate the improved AMS dating of the Orca Basin cores. Kennett, Elmstrom, and Penrose (1985) studied foraminifer assemblage composition from Orca Basin cores, chiefly EN32-PC6 and EN32-PC4. They use an age-depth model patterned after Leventer, Williams, and Kennett, but assign an age of 10,500 BP to the Y/Z boundary. They identify a glacial assemblage, replaced at about 16,000 BP by a meltwater-influenced assemblage, next replaced at about 12,000-10,500 BP (Younger Dryas) by a return of the glacial assemblage. They claim that by 10,500 BP "the oxygen isotopic data indicate attainment of Holocene surface-water temperatures" (Kennett, Elmstrom, and Penrose (1985:207). Late Holocene (post-5000 BP) assemblages indicate warmer temperatures than the early Holocene assemblages.

Figure 2.9 *(following on three separate pages).* Oxygen Isotope History of the Gulf of Mexico. A, core EN32-PC6, Orca Basin; B, core EN32-PC4, Orca Basin. Both panels adapted from Broecker *et al*. (1990:Fig. 7); radiocarbon assays listed are from Broecker *et al*. (1988:Table 1) and Broecker *et al*. (1990:Table 5) and are uncalibrated radiocarbon years with 400-year marine reservoir correction. Assays with question marks follow the data tables but depart from dates given in the original figure. Arrows denote meltwater pulses issuing from the Mississippi River. C, age-depth model for EN32-PC6 constructed from the tables cited above (no reservoir correction); note rejected assays that formerly were thought to indicate missing sediments. D, map showing location of cores in relation to Berger Bluff. Bathymetric contours are in meters. E, composite oxygen isotope history from 18,000 to about 800 RCYBP for LOUIS cores, offshore Louisiana (adapted from Aharon 2003:Fig 4, a); meltwater flood events (MWF) are those defined by Aharon (2003) and two of these correspond to Meltwater Pulses 1A and 1 B as defined by Fairbanks (1989). F, meltwater flux for the Mississippi River from 11,000 to 7000 RCYBP in cubic kilometers per year, showing post-Younger Dryas flood events (MWF; adapted from Aharon 2003:Fig. 7, a). This time span corresponds roughly to that recorded at Berger Bluff. In both panels E and F, the Younger Dryas is shaded; age model for E uses 400-year marine reservoir correction. G, oxygen isotope history for 13,000-7000 RCYBP in core RC12-10, offshore from Tamaulipas (data from Dowsett, Verardo, and Poore 2003:Appendix C). Dots represent two radiocarbon assays which are age-depth modeled as 9087 and 11,749 RCYBP but reported as 8950±40 and 11685±45RCYBP. H, reconstructed winter sea-surface temperature for the same core, based on transfer functions computed from foraminifer assemblages, for the period 14,000 to 540 RCYBP (adapted from Poore *et al*. 2003: Fig. 3). Note the major spike in both curves at 9000 RCYBP, and the lack of a recognizable Meltwater Pulse 1A. I, location map for core RC12-10 and the seven LOUIS cores.


Δ18O
+1 0 −1 −2 −3 −4‰
DEPTH BELOW CORE TOP (M)
1070?
10,510
11,840?
11,480?
13,570?
MWP 1A
EN32−PC6
a
Δ18O
+1 0 −1 −2 −3 −4 −5‰
DEPTH BELOW CORE TOP (M)
9110?
10,090
10,300
10,630
11,110
12,050
12,860?
MWP 1B
MWP 1A
EN32−PC4
b
THOUSANDS OF RADIOCARBON YEARS BP
0 2 4 6 8 10 14 18
DEPTH BELOW CORE TOP (M)
ASSAY
REJECTED ASSAY
EN32−PC6
c
95° 90°W
N30° 29° 28° 27° 26° 25°
Berger Bluff
Pigmy Basin
Orca Basin
ALKENONE EN32−PC4
SAMPLES EN32−PC6
1000
2000
3000
3600
Sigsbee Escarpment
0 100 KM
d
KMB 98


Δ 18O
−1
−2
−3
−4
−5
−6
RCYBP
2000
4000
6000
8000
10,000
12,000
14,000
16,000
18,000
MWF5
=MWP1B
YD
MWF4
=MWP1A
MWF3
MWF2
MWF1
LOUIS
e
MISSISSIPPI RIVER FLUX (KM3/YR)
1000
2000
3000
4000
7000
8000
9000
10,000
11,000
RCYBP
MWF5G
MWF5E
MWF5C
MWF5A
YD
f
KMB 03


Δ18O
+1 0 −1 −2 −3 −4
7000
8000
9000
10,000
11,000
12,000
13,000
RCYBP
YD
RC12−10
g
RECONSTRUCTED WINTER SEA SURFACE TEMPERATURE
16 18 20 22 24 26° C
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000
11,000
12,000
13,000
14,000
RCYBP
YD
RC12−10
h
95°
90° W
N30°
29°
28°
27°
26°
25°
24°
23°
22°
21°
20°
19°
Berger Bluff
LOUIS
RC12−10
0 200 KM
i
KMB 03

Flower and Kennett (1990) also studied foraminifer assemblage composition and isotope content from cores EN32-PC6 and EN32-PC4. They obtained seven AMS dates from the latter. The foraminifer assemblages indicated cold surface waters until 14,000 BP, warming until 11,600 BP, a temporary cold meltwater spike at 11,400 BP, continued cool surface waters from 11,200-10,200 BP, with Holocene warming thereafter; "surface water temperatures between 11.4 and 9.8 ka were similar to those marking the late glacial" (Flower and Kennett 1990:955). The oxygen isotope record integrates both the deglaciation history and the surface water temperature and suggests a meltwater spike from 14,000-10,800 BP, peaking at about 12,200-12,100 BP (Flower and Kennett 1990:Fig. 1; all of these dates are in uncalibrated radiocarbon years BP, with a marine reservoir correction). Flower and Kennett cite only 5 AMS dates for this core and apparently did not have available the full suite of dates cited by Broecker and others. Brown and Kennett (1998) place the meltwater spike at about 12,000-12,600 RCYBP.

Spero and Williams (1990) also restudied the same core (EN32-PC6), looking at 11 selected intervals in detail, and attempted to differentiate the effects of temperature and meltwater by using the ^{18}O chronology provided by Fairbanks (1989). They apparently had access to the first set of AMS assays cited by Broecker and others (1988), but do not comment on the proposed sedimentary hiatus. They calculated estimated annual temperature ranges for surface water (Spero and Williams 1990:Table 2), but the summer temperature estimates are far too high, higher even than modern temperatures, suggesting that the meltwater component has been underestimated. The data suggest that meltwater at 11,800 BP probably flowed year-round, then during the Younger Dryas was confined to the summertime, but resumed year-round flow afterward in the early Holocene.

Marchitto and Wei (1995) studied core EN32-PC4, using the chronology of Broecker and others, looking at the percentage of reworked calcareous nannofossils (Cretaceous and Tertiary fossils eroded from terrestrial deposits) as a measure of meltwater outflow. According to this measure, meltwater outflow was greatest (pulse IA) in the Bolling warm interval at 12,700-12,200 RCYBP uncal, declining until the beginning of the Younger Dryas. Contrary to other studies, they find no evidence of pulse IB after the Younger Dryas.

Several more recently studied cores have much better resolution and absolute dating control than these older studies. Aharon (2002; 2003) reports a series of seven piston cores from the Louisiana continental slope, northwest of the Orca Basin. A composite record from these seven LOUIS cores is estimated to extend from 18,400 to about 800 RCYBP; the oldest AMS assay is 16,000±270 RCYBP (Aharon 2003:Table 1; with 400-year marine reservoir correction). The sampling interval is 5-10 cm, with chronological resolution decades to centuries (Aharon 2003:page 3-7). These cores are closer to the meltwater outlet, and in an area with higher sedimentation rates than the Orca Basin, and the higher resolution and improved dating in these cores reveal a complex history of meltwater floods that was obscured in the earlier studies. Aharon defines five major meltwater flood (MWF) events (Fig. 2.9, E), two of which correspond to the meltwater pulses 1A and 1B recognized earlier by Fairbanks. The most prominent events are MWF2 at 13,600-13,200 RCYBP and MWF4 (or pulse 1A) at 12,250-11,200 RCYBP (Aharon 2003:Table 3). The cessation of meltwater during the Younger Dryas is also documented (Fig. 2.9, E, F). Aharon (2003:Table 3) designates this interval Pause 4, at 11,200-9,970 RCYBP.

Of even more interest is a series of four meltwater events designated MWF5A, MWF5C, MWF5E, and MWF5G between 9,970 and 8,900 RCYBP, during and after the Preboreal Oscillation (Aharon 2003:Table 3; "Late Paleoindian" in the Texas archeological chronology). These were recognized collectively in some of the earlier studies as Meltwater Pulse 1B, but in the LOUIS cores these can be discriminated as a series of separate flooding events. These continued to introduce significant volumes of glacial meltwater (although not as large as MWF 2 and 4) into the Gulf after the Younger Dryas, during a period when insolation was near its peak (Fig. 1.2, A). This must have served to maintain regional cooling to some extent, and to offset the effects of increased insolation. Table 2.4 lists the meltwater events that are relevant to the present study. Mississippi River discharge is listed in *sverdrups* (a sverdrup is a very large unit of discharge equivalent to a million cubic meters per second).

Table 2.4. Glacial Meltwater Flooding Events (condensed from Aharon 2003:Table 3, defined from LOUIS cores).

Flooding event (Aharon 2003)	Meltwater pulse (Fairbanks 1989)	Age (RCYBP)	Duration (radiocarbon years)	Flux (sverdrups)
MWF4	MWP1A	12,250-11,200	1000	0.15
MWF5A	MWP1B	9970-9870	100	0.07
MWF5C	MWP1B	9740-9660	80	0.07
MWF5E	MWP1B	9450-9290	160	0.10
MWF5G	MWP1B	9160-8900	260	0.08

The timing of these events was determined by meltwater releases from glacial Lake Agassiz into the Mississippi drainage, and the fact that meltwater was still being

released as late as 8900 RCYBP might suggest that hurricane development in the Gulf was delayed until after this date.

Another recently studied, high-resolution core (RC12-10) was obtained in the western Gulf, about 210 km east of the Tamaulipas shoreline, at N 23° 95.33° W. Unlike the other cores reviewed here, it records an area distant from sources of meltwater, and about five degrees of latitude south of Berger Bluff (Fig. 2.9, I). It was sampled in 1-2 cm increments, with eight AMS assays on foraminifera, ranging from 15,310±45 to 540±35 RCYBP (with a 400-year marine reservoir correction; Poore *et al*. 2003:Table 1). This core presents a very different isotope history. The isotope signal seems to be reversed, with a negative ^{18}O trend during the Younger Dryas and restrained positive trends when meltwater pulses are known to appear in the other records, such as the LOUIS cores (Fig. 2.9, G, based on data from Dowsett, Verardo and Poore 2003). The reason is unclear. Under present conditions, the inner shelf current flows north along the lower Texas coast in spring and summer, and southward in fall and winter. The fall/winter southward current transports fresh water from rivers along the northern Gulf (Morey *et al*. 2003).

Estimated winter sea surface temperatures are shown in Fig. 2.9, H. These are based on transfer functions developed by comparing foraminifer assemblages in sea-floor surface mud samples to water temperatures measured nearby. The most conspicuous feature is a dramatic warm spike at 9000 RCYBP that seems to coincide with MWF5G, listed above. Winter temperatures are 21-23° C before then, with the Younger Dryas marked by a subdued decline in temperatures (see the shaded band in Fig. 2.9, H). Most summer temperature estimates are near 29° C, but are not considered reliable because of poor inadequate core-top calibration for summer temperatures (Poore *et al*. 2003:page 26-

6). In general, the temperature changes indicated in the core are relatively small (Poore *et al*. 2003:page 26-5).

Although the Orca Basin and LOUIS cores have helped to clarify the meltwater and oxygen isotope history of the Gulf, a clear and well-dated warm-season temperature history is still lacking. Better temperature estimates come from a study (Jasper and Gagosian 1989) of unsaturated alkenones preserved in sediments from the Pigmy Basin, south of the Mississippi delta (Fig. 2.9, *D*). Alkenones are waxy organic compounds produced by marine algae, often coccolith-bearing species. The ratio of di-unsaturated (C37:2) to tri-unsaturated (C37:3) alkenones is known as the UK37 ratio, and the lower the ratio, the colder the surface water. The core (DSDP 619) studied by Jasper and Gagosian is dated by linear interpolation from three biostratigraphic boundaries (including the Y/Z boundary), the Y8 volcanic ash layer, and a single AMS date at about 24,000 BP (Jasper and Gagosian 1989:605-606). It comes from a deep (2259 m) basin on the continental slope.

Unfortunately, alkenone paleothermometry does not differentiate summer and winter surface water temperatures, so the estimated temperatures are presumably most comparable to annual averages; the estimated precision is about ±0.5° C. The estimates (Fig. 2.10) show surface temperatures rising to 21.3° C at 11,000 BP, falling to 20.2° C at 8500 BP, reaching a minimum of 19.9° C at 7500 BP, and rising thereafter to a high point of 25.6° C at 2900 BP. The older part of the curve corresponds reasonably well to the insolation curve (compare with Fig. 1.2, *A*), but the later Holocene aspect does not match at all. The alkenone temperature curve matches the shape of the oxygen isotope curve presented by Flower and Kennett (1990:Fig. 4) tolerably well, at least for the part

before 11,000 BP. At present, summer temperature runs about 4° C above the mean annual temperature, so if the same relationship prevailed in the past, the alkenone curve would indicate summer temperatures of 26° C (the critical level for hurricane formation) were not reached until about 6000 BP.

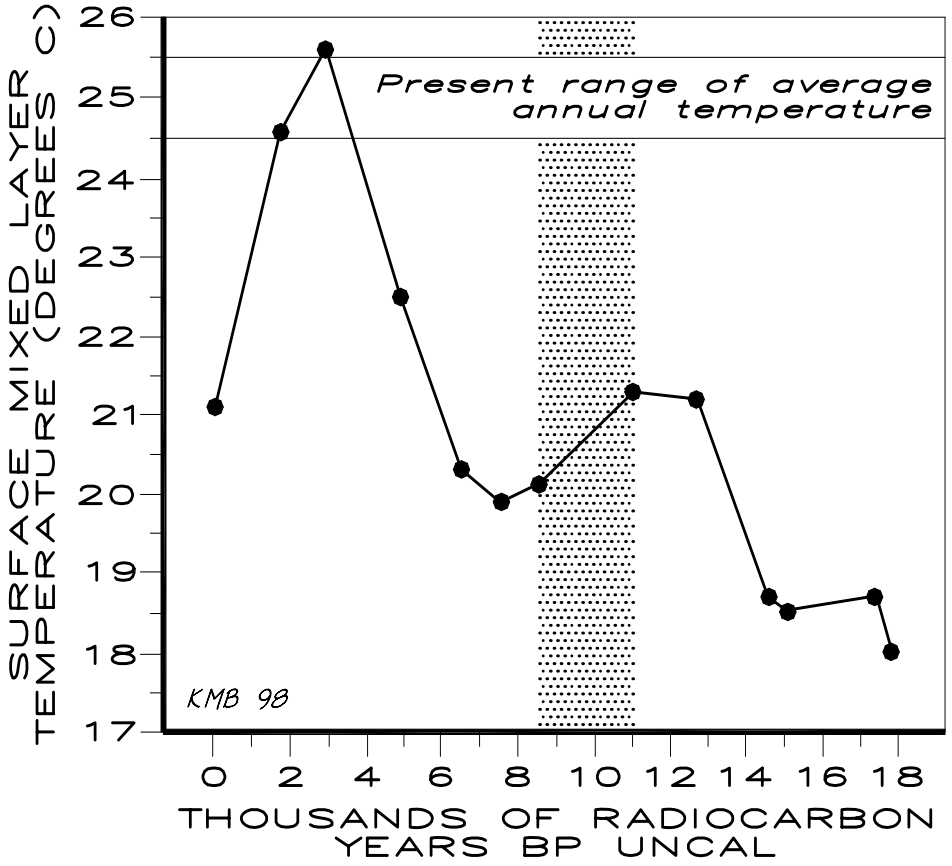


Figure 2.10. Alkenone Estimates of Surface Mixed Layer Paleotemperature in the Gulf of Mexico. Plotted here are part of the data from the Pigmy Basin published by Jasper and Gagosian (1989:Table 1); see text for details of age estimation, and previous figure for location of core. The most recent data point is 1800 BP. The critical heat level for hurricane formation is about 26º C, the top boundary of the graph; note that the curve presumably approximates annual temperature, not summer temperature, which is higher. Today's average annual temperature is about 24.5-25.5º C, shown as a horizontal band near the top. The vertical shaded band is the period spanned by the bench deposits at Berger Bluff.

Jasper and Gagosian draw attention to the fact that their estimates of the maximum difference between glacial and modern SSTs are about 8° C, in comparison to the 1° to 2° C difference calculated by Brunner and Cooley (1976), and suggest that their results are more useful as stratigraphic markers than as absolute temperature estimates. They may have unjustly discounted their own findings, however. The CLIMAP project in the 1970s followed Brunner and Cooley's estimate of a 1-2° C shift in tropical areas, but some of the latest research from tropical areas, both marine and terrestrial, suggests the shift varied between about 2° C and 5.5° C in different areas (Broecker 1996, Colinvaux *et al*. 1996, Thompson *et al*. 1998). Alkenone temperature estimates can be affected by dissolved nutrient concentrations (Epstein *et al*. 1998).

Another source of meltwater history is the alluvial record of the Mississippi River itself. The Laurentide ice sheet functioned like a two-way switch, alternately releasing meltwater to the St. Lawrence or to the Mississippi drainage, so that the meltwater histories of the two drainages are heavily antiphased (Marshall and Clarke 1999:309). During the Herman stage, Lake Agassiz contained about 10,900 km^3 of meltwater (Leverington, Mann, and Teller 2000:Table 1). A review by Saucier (1994b) indicates that meltwater flowed down the Mississippi from about 16,300 RCYBP to about 11,000 RCYBP uncal, when it was interrupted (during the Younger Dryas) by diversion into the St. Lawrence channel, followed by a final pulse of meltwater at roughly 10,000-9800 RCYBP uncal (this agrees very well with the Tahiti coral data). Porter and Guccione (1994) estimate the ages of these two meltwater pulses at 11,300-10,900 RCYBP uncal and 9900-9500 RCYBP uncal. A recent geomorphological study of the Lake Agassiz spillway in the Minnesota River has used radiocarbon dating to pin the end of the first pulse at 10,800 RCYBP and the end of the second pulse at 9400 RCYBP (Fisher 2003).

By then (Upper Campbell stage), Lake Agassiz was even larger (22,700 km^3; Leverington, Mann, and Teller 2000:Table 1), but furnished less outflow to the Mississippi. Additional physical evidence of glacial outwash in the Mississippi River valley is provided by the Charleston Fan, near Charleston, Missouri, which is not well dated but was likely formed close to 10,900 RCYBP, during meltwater pulse IA (Porter and Guccione 1994).

Gulf of Mexico water temperature history: summary

Insofar as the above history can be reconciled, there were several pulses of cold meltwater entering the Gulf of Mexico during deglaciation of North America, a major pulse (IA) during the Bolling-Alleröd warm period, a near cessation of meltwater during the cold Younger Dryas at 11,000-10,000 RCYBP, and a second, but much reduced pulse (IB) at the beginning of the Holocene, at perhaps 10,000-9800 RCYBP (or 9700-9100 RCYBP according to Aharon, 9900-9500 RCYBP according to Porter and Guccione, and before 9400 RCYBP according to Fisher). The second pulse resulted from a readavance of the Superior lobe of the ice sheet, which once again diverted meltwater into the Mississippi drainage. In addition, the high-resolution record from the Louisiana continental shelf suggests there were at least three additional pulses, the last of which (9,970 to 8,900 RCYBP) was actually a cluster of four discrete flood events.

That much seems clear, but when did average summer surface temperature in the Gulf rise to 26° C or greater (the critical point for hurricane formation)? The temperature estimates of Spero and Williams seem much too high to be plausible. The alkenone estimates of Jasper and Gagosian (Fig. 2.10) cannot be resolved into summer and winter components, and do not match the known meltwater history; a temperature peak at about

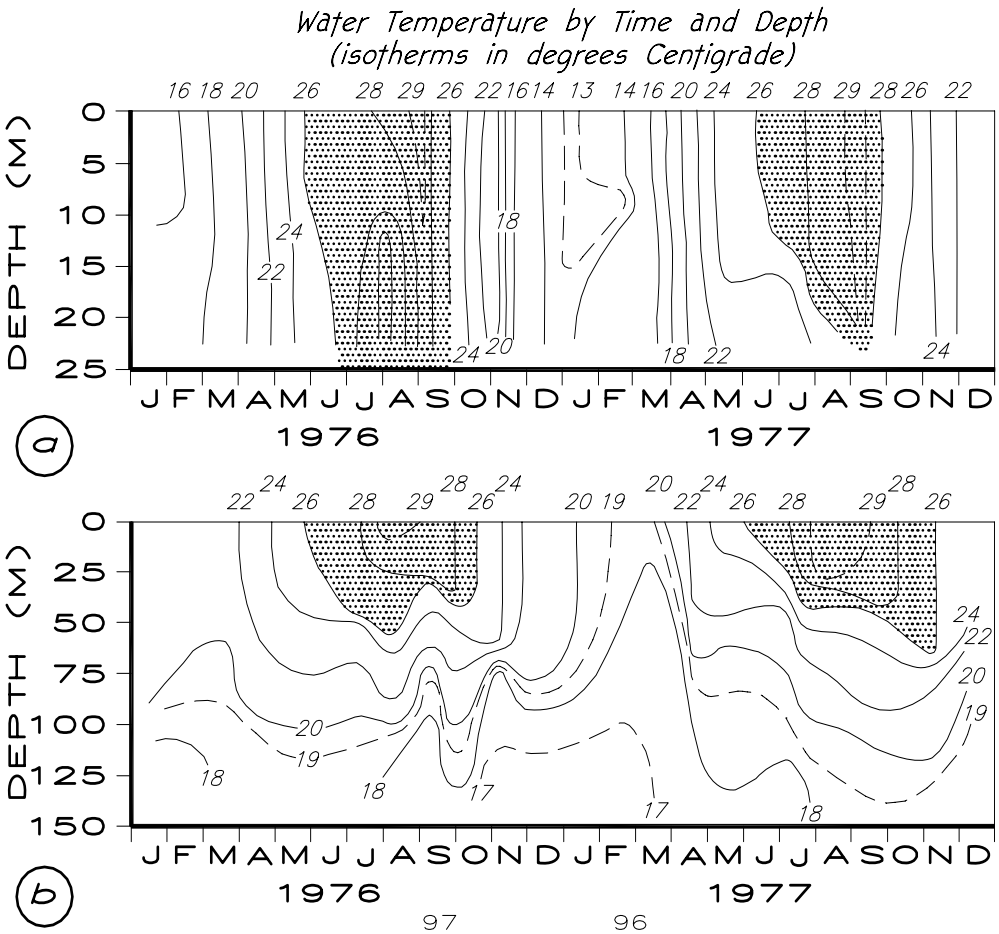
13,000-11,000 RCYBP actually occurs when the first major influx of cold meltwater is shown to have arrived in the Gulf. The transfer function-based estimates from core RC12-10 off Tamaulipas offer high resolution, but only for winter temperatures. About all that can be said with the information at hand is that the first 26° C summer temperatures were probably achieved sometime in the early Holocene, likely after pulse IB, and perhaps somewhat after 9000 RCYBP uncal. A date after 9000 RCYBP would follow the major warm spike shown in the Tamaulipas core, and would follow the final major meltwater episode ending at 8900 RCYBP in the cores from the Louisiana continental shelf.

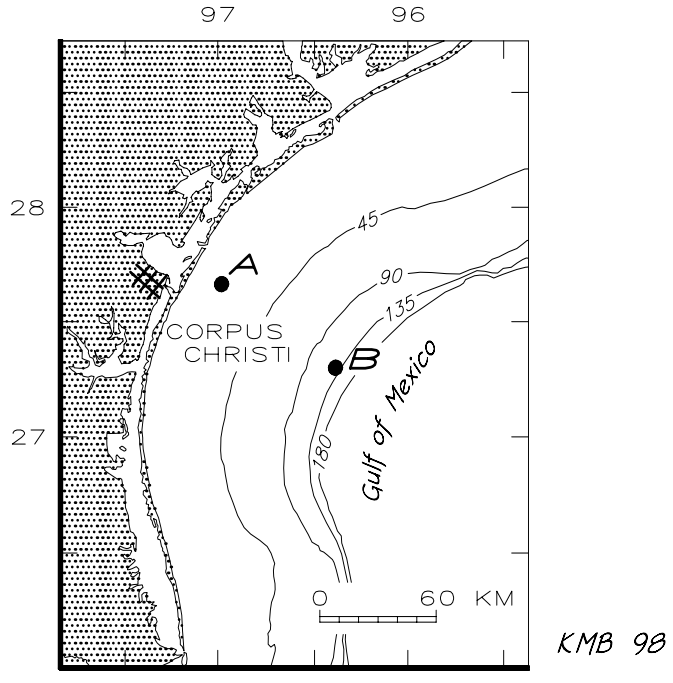
HURRICANE FORMATION IN THE GULF OF MEXICO

Hurricanes in the Gulf are fed by heat extracted from the water below, and as they move across the Gulf, they tend to follow tongues of warm water, leaving cooled water in their wake. Heat is the energy source for barometric pressure differences, winds, and transport of moisture. A significant pool of warm water is necessary, and although either a large mass of moderately warm or a smaller mass of very warm water will suffice, a sea surface temperature of 26° C is usually taken as the minimum temperature for hurricane formation (Leipper and Volgenau 1972:220). Wendland (1977) arbitrarily used the 80° F isotherm (26.8° C) as a unit of study, and found that tropical storms and hurricanes do not form in the North Atlantic unless the mean monthly area with temperatures of 26.8° C is at least 8,500,000 km^2 in size. Hurricane formation is more likely where warm water persists to considerable depth, generally about 60 m (Gray 1979:208). Direct measures before and after storms have shown that hurricanes can extract about 4000 calories/cm^2/day. The most likely area for formation of these large pools of warm water is in the central Gulf, due to periodic intrusion of very warm Caribbean water via the East

Gulf Loop Current (Leipper and Volgenau 1979:220; Chouinard, Liu, and Cooper 1997). Pools of warm water over the continental shelf do not form hurricanes, but they may help to steer one to a particular landfall along the coast. As Figure 2.11 shows, pools of warm water 26° C or higher in temperature may extend to depths as great as 60 m in warm years over the south Texas continental shelf, when they also may persist as late as early November (note isotherms for station "B" in 1977, off Corpus Christi).

Figure 2.11 *(following page)*. Water Temperature by Time and Depth in the Gulf of Mexico. Shown here are data for 1976 and 1977 from two stations offshore from Corpus Christi [adapted from Flint (1981:Fig. 3) and Brooks *et al*. (1981:Fig. 4)]. The area enclosed by the 26º C isotherm is shaded, and is noticeably deeper and more prolonged in 1977 than in 1976. Note difference in depth scale between stations “A” and “B.” Map shows location of sampling areas; contours in meters.


Water Temperature by Time and Depth
(isotherms in degrees Centigrade)
DEPTH (M)
0
5
10
15
20
25
J F M A M J J A S O N D J F M A M J J A S O N D
1976
1977
a
DEPTH (M)
0
25
50
75
100
125
150
J F M A M J J A S O N D J F M A M J J A S O N D
1976
1977
b


97
96
28
27
A
B
CORPUS
CHRISTI
45
90
135
180
Gulf of Mexico
0
60 KM
KMB 98

Hurricanes in the northern hemisphere mostly form somewhat south of the N 20° parallel (Gray 1979:Fig. 8), but a significant number either form in the Gulf or enter it. At present, the chief months for northern hemisphere hurricane development are July, August, September, and October, with a long-term average of 11.5 hurricanes/month in September (Fig. 2.12, based on Gray 1979:Table 2). The most severe tropical storms on the south Texas coast have arrived in August and September (Berryhill n.d.: Table 5).

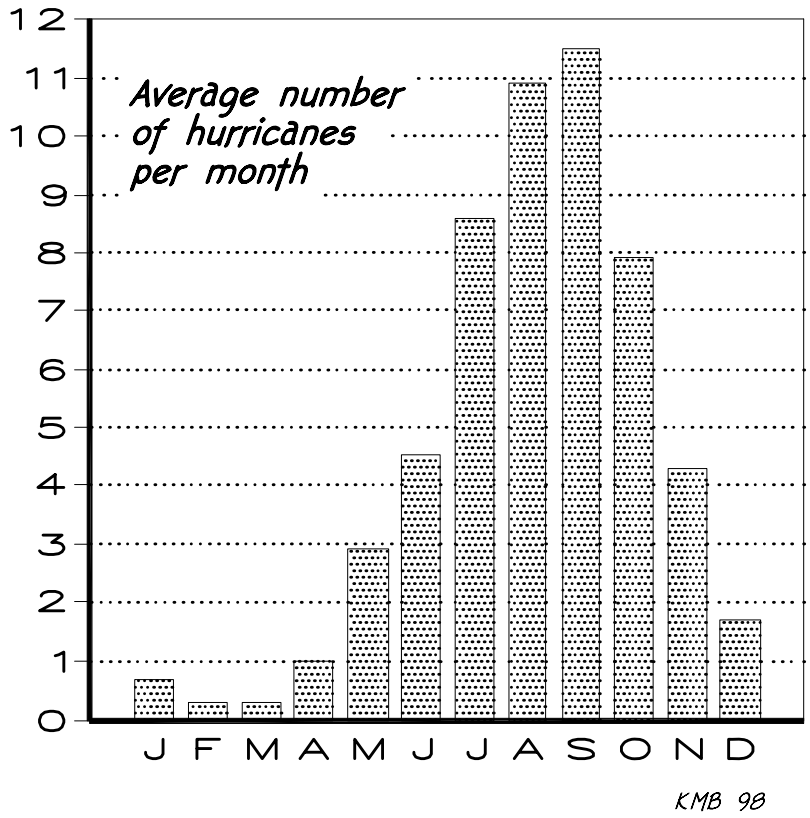


Figure 2.12. Average Number of Tropical Cyclones Per Month in the Northern Hemisphere. Data for 1958-1977, from Gray (1979:Table 2). Compare this distribution with that of water temperature shown in the previous figure.

These, of course, are the months when pools of warm water are available (Fig. 2.11 and Berryhill n.d.: Fig. 19, 23). The significance of the insolation maxima discussed in Chapter 1 should now be apparent. Although average annual insolation peaked at about 10,000 RCYBP uncal (Fig. 1.2, A), August and September insolation did not peak until after 8000 RCYBP uncal (Fig. 1.4). This. combined with limited amounts of meltwater persisting until 9800 RCYBP uncal or later, suggests that hurricanes were probably absent from the Gulf until the early Holocene (somewhere in the span 8000-9800 RCYBP). On the other hand, since August and September insolation levels were actually higher than at present from about 10,000 BP on, these early Holocene hurricanes may have been more severe than contemporary examples. The monsoonal climates of the eighth, ninth, and tenth millennium before present may have produced some very severe tropical cyclones in the Gulf of Mexico. Recall, also, that contemporary hurricanes are uncommon in *El Niño* years because strong westerly winds aloft shear off the tops of tropical cyclones before they can develop. Strong winds aloft are thought to have been characteristic of the Pleistocene as well, and are another reason for supposing that hurricanes are essentially a Holocene phenomenon.

Geological evidence of such storms in coastal environments is, of course, now submerged. Holocene deposits thought to be hurricane-produced have been found (Davis, Knowles, and Bland 1989; Donnelly *et al*. 2001; Liu and Fearn 1993, 2000a, b; Scott *et al*. 2003), but they are mostly Late Holocene in age. One study of vibracores in Apalachicola Bay, Florida, identified at least five separate discontinuities in grain-size parameters that were thought to be evidence of major storm events. These occur below woody material radiocarbon assayed at 7340 and 7990 RCYBP uncal (Isphording and Isphording 1991:Fig. 3). Peaks in storm-derived inwash layers have been found as far

back as about 10,240 RCYBP (11,900 cal BP) in lakes in Vermont and New York, but there are several types of storms besides tropical disturbances that might have been responsible (Noren *et al*. 2002). A simulation study by Hobgood and Cerveny (1988) suggested the Full Glacial sea surface contained enough heat energy to sustain "minimal" hurricanes, although they were less severe than modern storms. Their study, however, was based on CLIMAP temperature estimates that are probably too high, and it does not include the meltwater-influenced Gulf of Mexico. Inoue and Welsh (1996) have done a numerical simulation of Gulf oceanic circulation under last Glacial Maximum conditions (before major meltwater input), but they, too, use CLIMAP data. Their simulation produces a larger anticyclonic gyre off the Texas coast in both summer and winter (Inoue and Welsh 1996:Fig. 34b, 35b), and it shows most of the western Gulf with temperatures above 26° C at the surface, but not at 40 m or below (Inoue and Welsh 1996:Fig. 40). The Loop Current is weaker in their full glacial simulation, introducing less warm water than at present. Because the Glacial Maximum simulation predates the major meltwater spikes, uses CLIMAP temperature estimates that are probably not low enough, and uses a model level boundary set at 40 rather than 60 m, there is probably nothing in either of these simulation studies to suggest the presence of Pleistocene-aged hurricanes.

OTHER PALEOENVIRONMENTAL SITES IN THE GUADALUPE-SAN ANTONIO RIVER BASINS

Sources of paleoenvironmental information for the transition to the Holocene in the Guadalupe-San Antonio river basins are few, especially in the lower basins. Some of these are shown in Fig. 1.26. The most important sites are a pair of peat bogs at Ottine (Hershop and Soefje Bogs), an archeological site (Richard Beene) at San Antonio, a sinkhole (Winston's Cave) at Camp Bullis, and a cave site (Hall's Cave) with paleontological data at the head of the Guadalupe River basin in Kerr County. Besides these, there are a few other paleoenvironmental sites, but they mostly pertain to later parts of the Holocene. Some limited information is available from the River Spur site in Victoria, and from Friesenhahn Cave, near Bulverde.

Besides supplying different kinds of proxy environmental indicators, these different classes of sites have different accumulation histories. In contrast to alluvial sites, which often have sedimentation rates that decline as time progresses, sedimentation rates in Central Texas sinkholes may be episodic or may have accelerated in the Holocene. At Hall's Cave, for example, the time resolution seen in the late Holocene part of the record is not nearly as detailed for the Pleistocene-Holocene transition. Peat bogs may have accumulation rates that are apparently linear (Hershop Bog) or markedly declining through time (Patschke Bog), which gives much better time resolution for the Pleistocene-Holocene transition.

South Soefje Bog (Gonzales County)

This is one of a cluster of sphagnum peat bogs at Ottine (Chelf 1941), 96 km to the west-northwest of Berger Bluff. This unique area has a number of disjunct or relictual Austroriparian plant and animal species (Graham 1958:38; Raun 1959; Fullington 1974) and is not floristically representative of the lower Guadalupe River basin now. Alan Graham collected a core in 1957 from a site he called South Soefje Bog, and obtained a single radiocarbon assay (Humble Oil and Refining Company, run 501) of 7820±350 RCYBP uncal from the base, which presumably means a depth of 4.7 m. The core was divided into 5 cm increments, but only every other increment was analyzed for pollen (47 samples). J. Potzger and B. Tharp had apparently sampled both this bog and another called North Soefje Bog some years earlier, but had never published the results (Graham 1958:8). Bryant (1969:45) also collected a core in April, 1967, designated South Soefje Bog, although according to the landowner, not the same one sampled by Graham. Bryant's core was 4 m deep, divided into 10 cm increments, and is undated.

Graham and Bryant obtained similar results. Both cores have relatively uniform pollen spectra from top to bottom, with rather small variations at various levels, indicating vegetation similar to that of the present. Since the base of Graham's core appears to lie at 7470-8170 RCYBP (at 1δ), apparently both cores extend no farther back than the early Holocene. Graham reports a single grain of sweetgum (*Liquidambar* sp.) at the 3.9 m level (Graham and Heimsch 1960:Table 1), and Bryant (1969:84) reports hazelnut (*Corylus* sp.), which is now extirpated in Texas. The latter consists of single grains at 2.0-2.1, 2.1-2.2, and 3.7-3.8 m. Oak, grasses, ragweed, pecan/hickory, composites, ash, sedges, Umbelliferae (Apiaceae, or carrot family, such as hemlock), and

pine are among the most common pollen types for the section as a whole. Spruce and fir pollen was not found.

Hershop Bog (Gonzales County)

This bog lies south of Soefje Bog and is considerably deeper. In 1967-68, Tom Patty and Vaughn Bryant collected two cores (5.4 and 5.0 m deep, spaced 10 m apart) from Hershop Bog; Patty also obtained another from a bog he designated East Hershop Bog (Patty 1968:41-42). The deepest core (I) was analyzed in 54 increments of 10 cm each and was surrounded by five additional cores used for radiocarbon sampling. The radiocarbon samples were 20 cm increments, an upper increment collected at 0.3-0.5 m, middle increment at 2.3-2.5 m, and a lower increment in each radiocarbon sampling probe. The lower increments vary somewhat from probe to probe (two at 4.8-5.0, one at 4.4-4.6, and two at 4.9-5.1 m). Fifteen assays were produced this way (Patty 1968:Table 1; Valastro and Davis 1970), but due to the sampling plan these are grouped into three groups of five duplicate samples each, so that major intervening segments of the cores are left undated. The lower group assayed about 10,576±77 RCYBP uncal and the middle group 6004±51 RCYBP uncal, according to CALIB 3.03 weighted averages.

Patty reports that there are no major intrusions of clastic sediment in the peat, and the three blocks of assays suggest a near-linear accumulation rate. In view of this, it may be permissible to try to interpolate dates for major changes in the pollen spectrum. I have used curve-fitting with the top of the bog fixed at zero years BP. The assays are not weighted by standard error. The resulting curve (Fig. 2.13) does not differ greatly from a linear solution, except perhaps at the ends of the curve. At the base of the curve, the fitted curve suggests slower deposition rates, but it is not clear if this part of the model is

appropriate. Patty (1968:13) reports that sand (evidently with no pollen recovered) was found at the base of the core from 5.4 to 5.5 m. In any case, the part of the curve after 11,000 RCYBP should be reasonably accurate. The age model used here is defined as

$$\text{depth (m)} = a + b\,x^2 * \log_{(\text{base e})} x + c\,x^3$$

where a = 0.068926139

b = 0.11718496

c = 0.000062160465

x = age in radiocarbon years

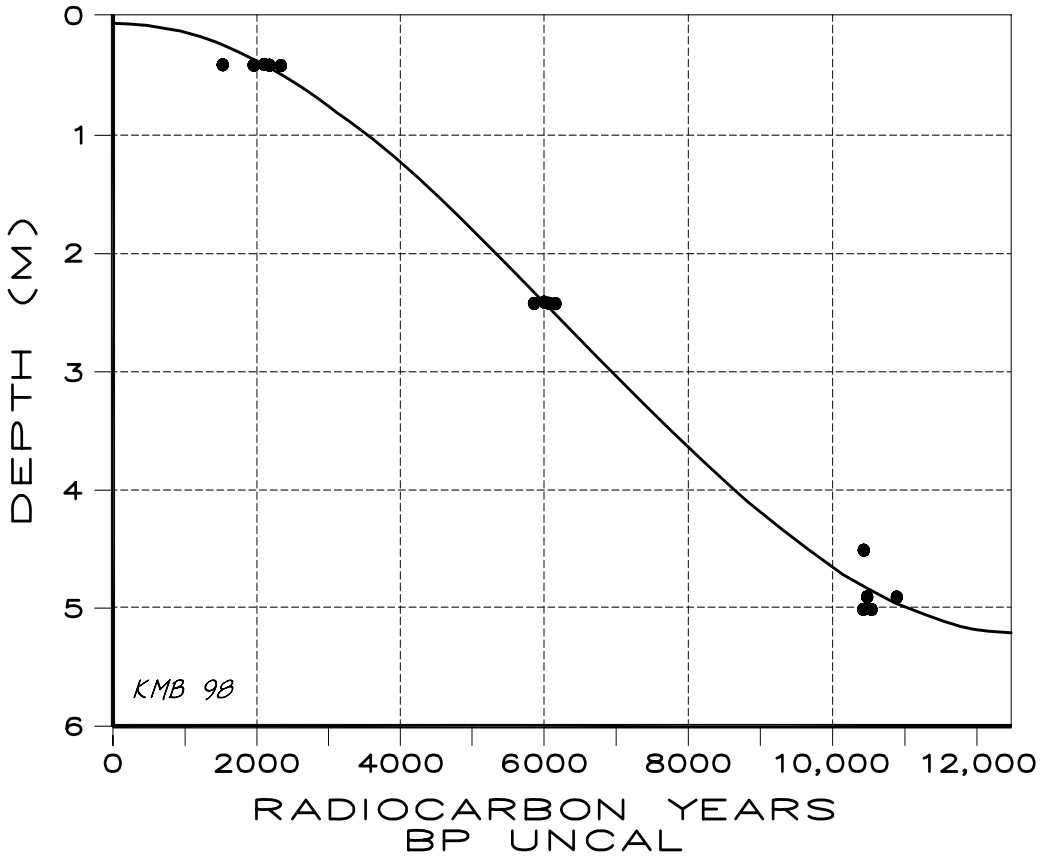


Figure 2.13. Age-Depth Model for Hershop Bog. Radiocarbon assays (dots) plotted are uncalibrated dates from Patty (1968:Table 1), with the age at the surface assumed to be zero years BP. Fitted curve is described in the text.

Unless noted otherwise, dates cited in the following discussion are estimates from the fitted curve. The age-depth model suggests the base of the bog dates to the very end of the Bolling-Allerod period at about 11,730 RCYBP uncal, and the Younger Dryas should be represented by deposits from 4.78-5.19 m.

Birch pollen was found from the base of the core up to the 4.7 m level (about 9842 RCYBP uncal), when it was apparently extirpated from south Texas. The birch peak occurs at about 10,500 BP (Fig. 2.15, B). The birch pollen, identified as *Betula nigra* (river birch; Larson, Bryant, and Patty 1972:365, may very well be an indicator of a mesic Younger Dryas interval. As its name indicates, river birch is a riparian species. It grows in the southeastern US where optimum annual rainfall is about 100 cm (range, 71.5-162.0; Thompson, Anderson, and Bartlein 1999). Alder pollen (*Alnus* sp.) was found sporadically in slight quantities throughout the core, but is somewhat more frequent in the bottom part; it is another member of the birch family that is now regionally extirpated (*Alnus serrulata* is found in east Texas today and is another riparian taxon). Patty designates the lowest part of the core from the base to 4.7 m as his "birch pollen zone." It is marked by moderate levels of birch, elm, and oak pollen, relatively little grass pollen, and very little pollen from the Umbelliferae. Sweetgum pollen was found at the 5.2 m level (about 11,035 BP). The "birch pollen zone" covers the end of the Bolling-Allerod, all of the Younger Dryas, and part of the first two centuries of the Preboreal. Patty also notes

> Analyzed samples from a 0.5-m core taken from the bottom (5.2-5.7 m) of a recently discovered peat deposit designated by this writer as East Hershop Bog has revealed a pollen sequence which parallels the Hershop profile....The birch pollen peak occurred at the 5.7-m level and gradually decreased upwards. Most of the other pollen types were observed at all levels but the birch pollen was absent above the 5.0-m point. Radiocarbon dating of the East Hershop Bog was not obtained and stratigraphic correlation will not be attempted (Patty 1968:41-42).

A plot of the arboreal/non-arboreal (AP/NAP) pollen ratio in the main Hershop Bog cores shows tree pollen peaking at about 10,386 BP, then declining rapidly to 9741 BP (Patty 1968:Fig. 8); grass pollen peaks at 3.8 m (Patty 1968:Fig. 7), or about 8312 BP. In summary, the Hershop Bog cores seem to document fairly fast regional drying over a transitional period lasting some 650 years, beginning at the Younger Dryas peak, about 10,400 RCYBP uncal. Larson, Bryant, and Patty (1972:366) summarize this as "a change from an upland parkland to savannah vegetation, and an associated change from a closed to open canopy forest in the more mesic flood plain areas." Huisache and mesquite are important components of the regional vegetation (huisache is more characteristic of the Berger Bluff catchment to the east-southeast), but *Acacia* pollen was found only in modern surface samples. *Prosopis* pollen was found in surface samples and the topmost 10 cm core sample.

Vaughn Bryant also studied the same 5.4 m core analyzed by Patty, but he examined 28 samples extracted at 20 cm intervals (Bryant 1969:87). Curiously, he found insufficient pollen for study in the upper 80 cm; no explanation for the discrepancy between this and Patty's results is given. Otherwise, the results are very similar to but not identical to Patty's. Bryant found a few taxa not reported by Patty (*Populus*, *Vitis*, *Rhus*; see Bryant 1969:Fig. 10). A single sweetgum grain was found at 2.8 m.

Further examination of the Hershop Bog pollen counts

A subset of the original pollen counts produced by Patty have been placed in the North American Pollen Database (NAPD) and is available for downloading from the World Wide Web. This data set is for the 70 most common pollen types found throughout

North America, so some of the original categories have been combined (*Typha*, for example, is reported by Patty but does not appear as a separate type in the NAPD). I have extracted some of these counts, standardized them by the total grain count per sample, and plotted them against the age-depth model shown in Fig. 2.13. Figure 2.14, *A* shows the number of taxa in the NAPD data set over time. This is not the total number of taxa originally recorded by Patty, but the categories are consistent from sample to sample. Species richness shows a long initial decline that appears to coincide closely with the time span of the Berger Bluff bench deposits. Perhaps both better pollen preservation in the lower levels of the bog, where conditions may have been more consistently anaerobic, and greater taxonomic diversity in the Late Pleistocene are responsible for the shape of the oldest part of the curve. Figure 2.14, *B* shows, for each sample, the number of taxa plotted against the grain count. The lack of structure in the swarm of points suggest sample size does not strongly influence diversity. Later chapters will show this is not always the case for other kinds of proxy data, and in some cases rarefaction methods may be necessary to investigate species richness. In any case, I conclude that the older part of the bog section is not strongly biased by taphonomic factors.

Figure 2.14 *(following page)*. Hershop Bog, Species Richness. *A*, number of taxa per sample over time. Data from Patty (1968) as tabulated in North American Pollen Database, 70 Common Pollen Types (partial roster of taxa). Sample ages estimated by age-depth model in Fig. 2.13. Shaded area approximates Berger Bluff bench time span. *B*, number of taxa in NAPD by sample size. Each point is a single sample; note that the swarm of points is too homogeneous to fit a rarefaction curve.

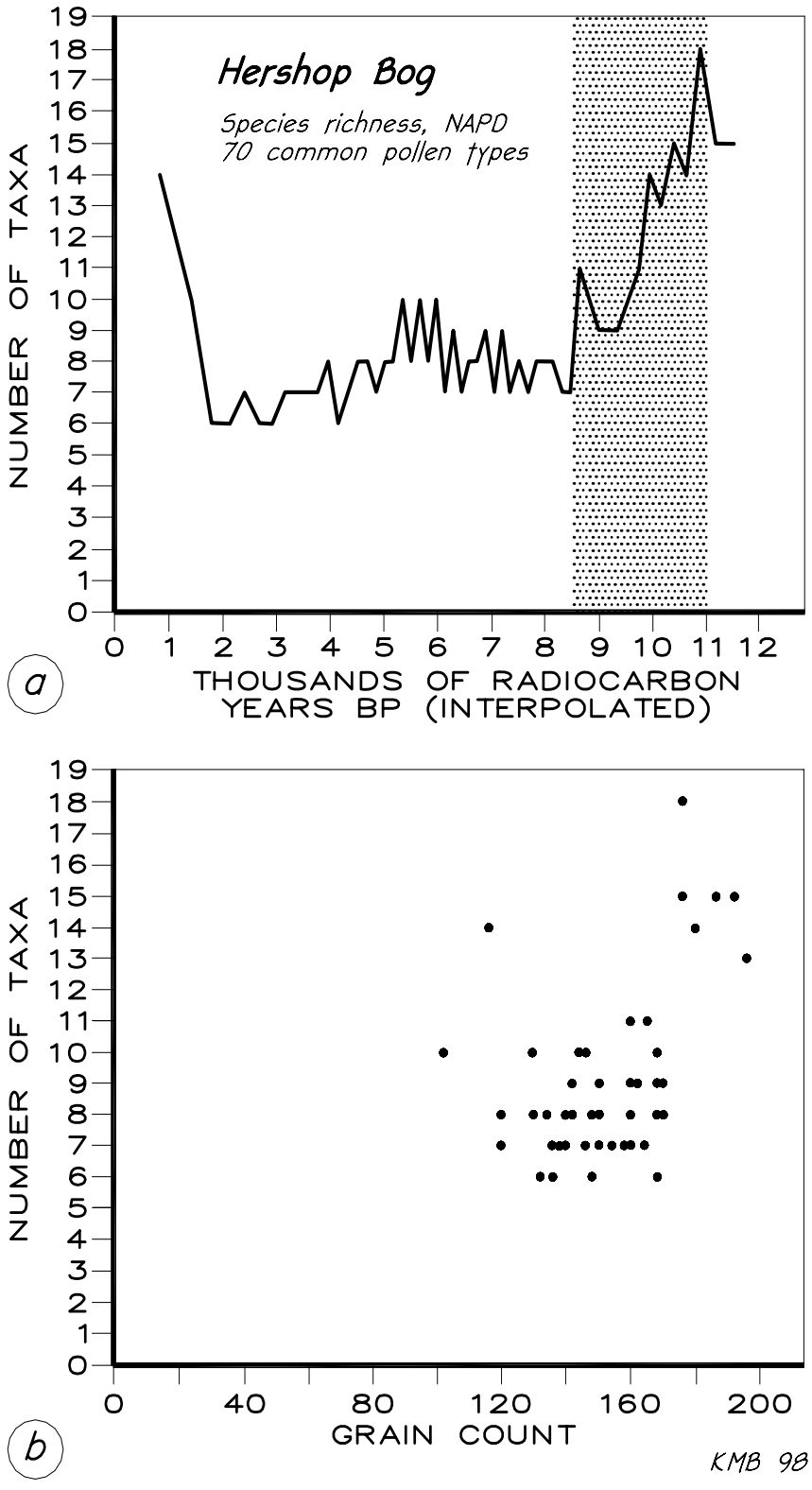

Hershop Bog
Species richness, NAPD
70 common pollen types
NUMBER OF TAXA
0 1 2 3 4 5 6 7 8 9 10 11 12
THOUSANDS OF RADIOCARBON YEARS BP (INTERPOLATED)
a
NUMBER OF TAXA
0 40 80 120 160 200
GRAIN COUNT
b
KMB 98

Figure 2.15, *A* shows grass and oak pollen. Oak shows a long decline beginning before the Younger Dryas and continuing until about 8500 RCYBP uncal. Grass pollen begins a sharp increase at the end of the Younger Dryas (10,000 RCYBP uncal), peaking at about 8000 RCYBP, suggesting a period of marked prairie expansion and reduction in tree canopy in the early Holocene.

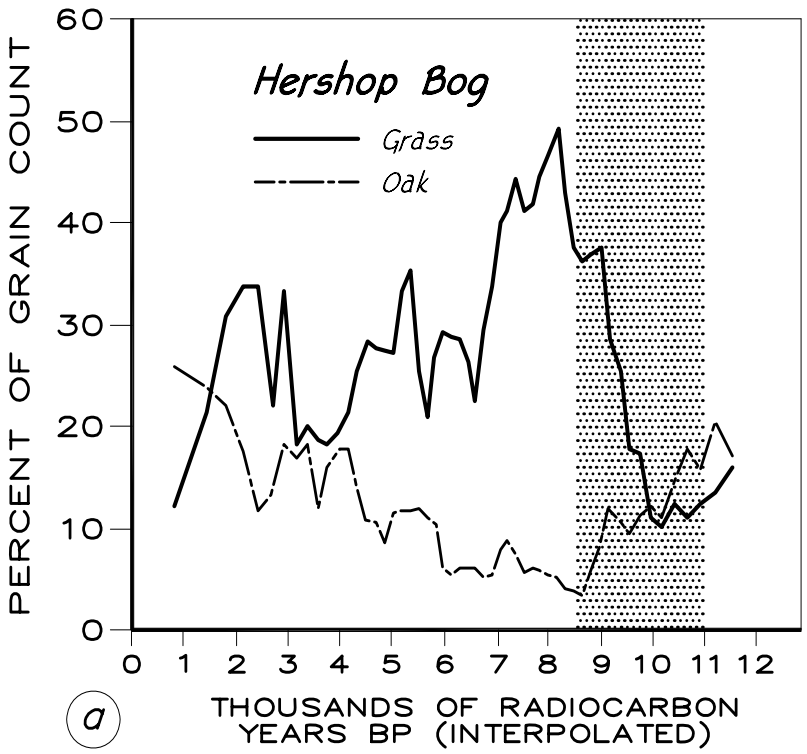
In Fig. 2.15, *B,* arboreal pollen types are divided into bog-dwelling or *riparian* trees (alder, birch, elm, and willow) and non-bog-dwelling or *"upland"* trees (ash, hackberry, hickory/pecan, maple, pine, oak, sweetgum, and walnut). Actually, most of the latter taxa are quite at home on floodplain terrain, and in that sense could also be considered riparian trees, but they are not likely to be found in boggy habitats. Hackberry, for example, commonly borders streams in upland areas, but is not as likely in swampy habitats. Fig. 2.15, *B* shows riparian trees peaking in the Younger Dryas, then nearly vanishing at 9171 RCYBP uncal. "Upland" trees peak at the beginning of the Younger Dryas, declining throughout the period represented by the bench deposits, reaching a minimum at about 8500 RCYBP uncal. This curve is essentially the same as that for oak shown above.

Figure 2.16, *A* repeats the oak pollen curve and shows another curve for sedges (Cyperaceae), which ought to be an adequate index of groundwater conditions in the bog. Sedge pollen shows a peak at 8645 RCYBP uncal, followed by a sharp drop until about 8312 RCYBP uncal. This decline (modeled here as lasting about 330 years at Hershop Bog) matches almost exactly the evidence for cessation of spring discharge at Berger Bluff, and presumably represents regional drying and lowered water table levels. One

thing that is not clear, however, is why the riparian tree pollen decline seen in the previous figure should significantly anticipate that of the sedge pollen.

Figure 2.16, *A* also shows that sedge and oak pollen are positively correlated until about 7500 RCYBP, after which they are negatively correlated. The reason for this is likewise unclear. Presumably almost all of the oak pollen is from postoak and blackjack oak, species that grow on well-drained, sandy terrain around the bog. One might expect positive correlation between the sedge and oak curves throughout the Holocene, since both should perhaps respond positively to increases in effective moisture.

Figure 2.15 *(following page)*. Hershop Bog, Grass and Arboreal Pollen Distribution. *A*, grass and oak pollen; note evidence of marked prairie expansion at about 7000-10,000 BP. *B*, *"upland"* (non-streamside) trees (ash, hackberry, hickory/pecan, maple, pine, oak, sweetgum, walnut) and *riparian* trees (alder, birch, elm, willow). Counts from Patty (1968) as tabulated in NAPD, 70 Common Pollen Types, standardized by total grain count per sample. Sample ages estimated by the age-depth model in Fig. 2.13. Shaded area approximates Berger Bluff bench time span.


Hershop Bog
Grass
Oak
PERCENT OF GRAIN COUNT
0
10
20
30
40
50
60
0 1 2 3 4 5 6 7 8 9 10 11 12
THOUSANDS OF RADIOCARBON YEARS BP (INTERPOLATED)
a

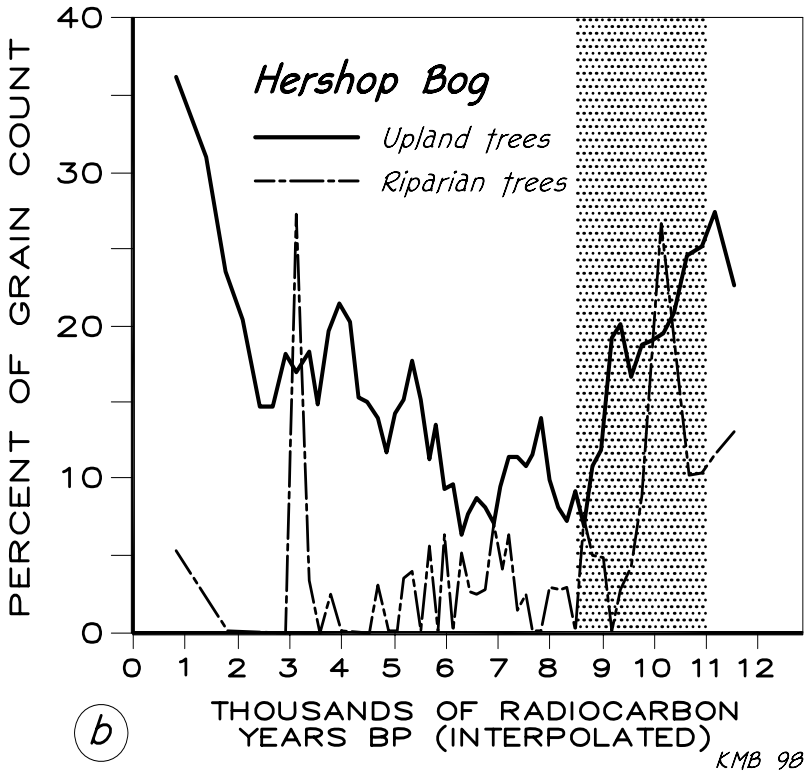
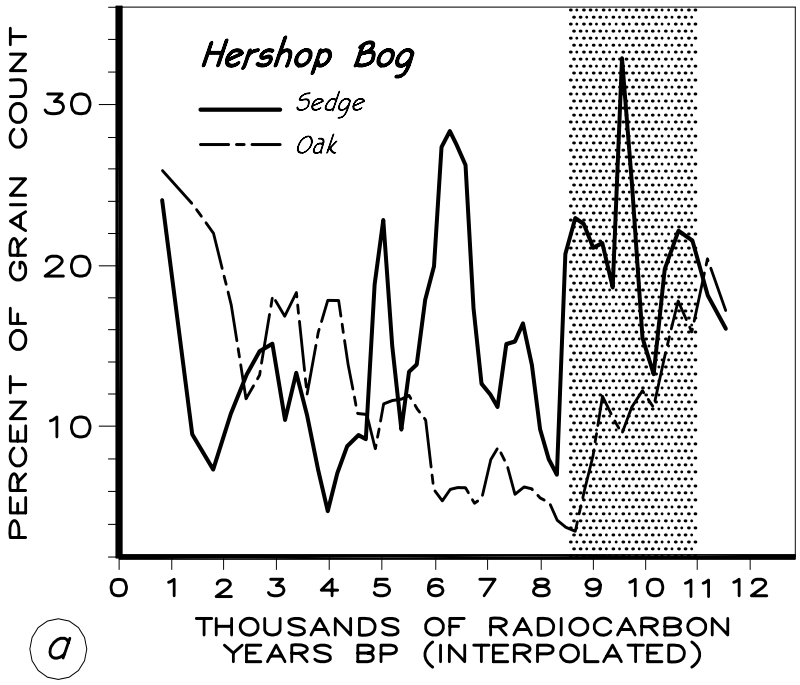

Hershop Bog
Upland trees
Riparian trees
PERCENT OF GRAIN COUNT
0
10
20
30
40
0 1 2 3 4 5 6 7 8 9 10 11 12
THOUSANDS OF RADIOCARBON YEARS BP (INTERPOLATED)
b
KMB 98

Figure 2.16 *(following page)*. Hershop Bog Sedge, Oak, Birch, and Alder Pollen Distribution. *A*, sedge and oak pollen are positively correlated from the base of the core up until about 7000 BP, after which they are negatively correlated. *B*, birch and alder, both probably bog components. Birch peaks during the Younger Dryas, but disappears at an interpolated age of about 9544 BP, at the onset of the Boreal interval. Alder shows no significant patterning. Counts from Patty (1968) as tabulated in NAPD, 70 Common Pollen Types, standardized by total grain count per sample. Sample ages estimated by the age-depth model in Fig. 2.13. Shaded area approximates Berger Bluff bench time span.


Hershop Bog
Sedge
Oak
PERCENT OF GRAIN COUNT
10
20
30
0 1 2 3 4 5 6 7 8 9 10 11 12
THOUSANDS OF RADIOCARBON YEARS BP (INTERPOLATED)
a

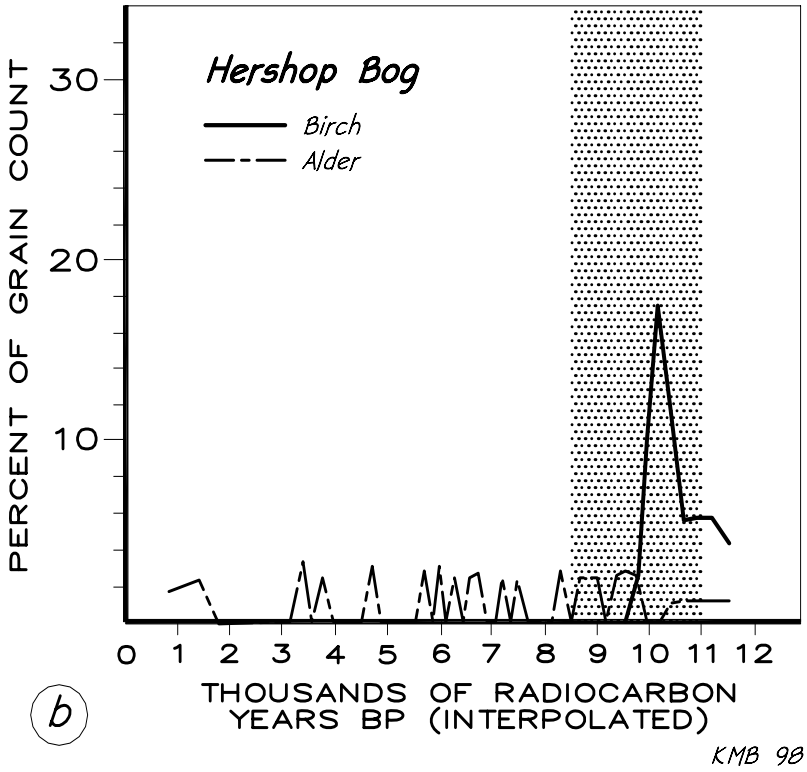

Hershop Bog
Birch
Alder
PERCENT OF GRAIN COUNT
10
20
30
0 1 2 3 4 5 6 7 8 9 10 11 12
THOUSANDS OF RADIOCARBON YEARS BP (INTERPOLATED)
b
KMB 98

Figure 2.17 shows the distributions of Apiaceae (carrot family, formerly Umbelliferae) and Asteraceae (sunflower family, pioneer plants in disturbed habitats) pollen. The Apiaceae peak in the late Holocene at about 3575 RCYBP, but are absent or scarce in the earliest samples. The Asteraceae show three intervals (at about 825-3160, 5340-5970, and 7830-8480 RCYBP) of rapid increase followed by equally rapid decline.

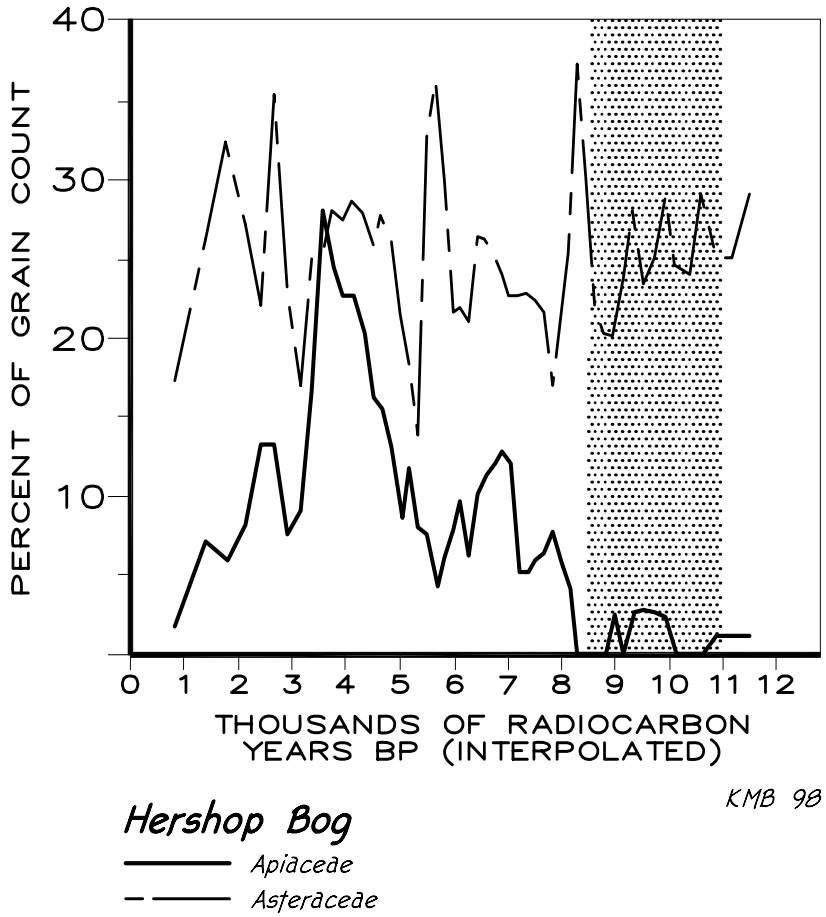


Figure 2.17. Hershop Bog, Pollen Distribution for Apiaceae and Asteraceae. The Apiaceae (formerly Umbelliferae, carrot family) show a distinct peak in the late Holocene. The Asteraceae (sunflower family), pioneers in disturbed habitats, show three intervals of rapid fluctuation at about 1000-3000, 5500, and 8500 BP. Counts from Patty (1968) as tabulated in NAPD, 70 Common Pollen Types, standardized by total grain count per sample. Sample ages estimated by the age-depth model in Fig. 2.13. Shaded area approximates Berger Bluff bench time span.

These presumably represent intervals of time (about 630 years or longer) during which significant areas of disturbed habitat were first created, then revegetated by climax associations. The first of these begins at about 8480 BP, or roughly coeval with the top of the bench deposits at Berger Bluff. This pollen type seems to show the clearest evidence of possible cyclic frequency fluctuations.

Comments on bog palynology

Most of the principal Texas bogs that have been studied have few radiocarbon assays. So far as I know, the only site where semi-close-interval dating has been applied is Patschke Bog, where a set of 19 assays was obtained by Tom Stearns (reported by Camper 1991:Table 2). There are many examples of date inversions in this series. The most strikingly erroneous assay is one at 2255 BP bracketed by an assay of 15,220 BP below and 17,290 BP above. Erroneous peat dates like these may be far more common than anyone realizes (see Shore, Bartley and Harkness 1995), because if only one to three widely spaced assays are obtained per core, the likelihood of an inversion is quite low, no matter how erroneous the assay. If other bogs were as intensely assayed as Patschke Bog, we might find an equally alarming number of erroneous dates. This probably applies even where duplicate assays are run, as at Hershop Bog, because if chemical contamination is the problem, duplicate assays are likely to furnish duplicate errors. Small samples of peat separated into different fractions (alkali-treated peat, untreated peat, and moss fragments) have furnished AMS radiocarbon dates that differ by as much as 365 to about 1000 years (Nilsson *et al*. 2001). Some instances are also known of peat bogs showing a "reservoir effect" similar to marine reservoir age offsets, in which peat samples may assay as much as 200-250 years older than the true radiocarbon age (Kilian, van der Plicht and van Geel 1995; Pancost, Baas, and Damsté 2000). The mechanism is poorly understood, but may

involve the evolution of methane gas from older deposits at the base of the bog. Peat samples can also assay anomalously young if stored wet and contaminated by fungal growth (Wohlfarth *et al*. 1998) or if contaminated by younger penetrating plant roots. The obvious conclusion is that researchers should be cautious about placing too much faith in the chronologies of any of the existing bog cores. That applies to the age model used here for Hershop Bog, as well.

Peat bogs have usually been approached interpretively by looking for consonant changes in frequency distribution that affect large parts of the pollen spectrum, drawing boundaries between "pollen zones" where several taxa seem to increase or decrease in concert, as Camper has done at Patschke Bog. This approach views a biotic assemblage or community as an *ecological system* responding to climatic stages. However, most biologists now feel that both plants and animals show individualistic responses to climatic change, and if one of the pollen diagrams is examined, it can be seen that nearly all taxa show frequency fluctuations, but the fluctuations are not synchronized.

The chronology for Patschke Bog, in Lee County, appears to resemble that for Hershop Bog fairly well (Camper 1991:Fig. 3). The Holocene increase in grass pollen appears to begin here at about 10,000 RCYBP uncal as well; however, here oak pollen increases at the same time as grass. Sedge pollen, which is variable in the Holocene at Hershop Bog, increases in much the same way as grass and oak pollen. Birch becomes uncommon at roughly 8200 RCYBP, disappearing at roughly 5500 RCYBP, which is later than at Hershop Bog. At Boriack Bog, the Holocene increase in grass pollen appears at perhaps about 8500 RCYBP [Bryant 1969:Fig. 7; or slightly later according to Bousman (1994)], while birch pollen is simply uncommon throughout.

There seems to be no sharply defined Younger Dryas pollen signal in any of these bogs. The period is characterized by an abundance of arboreal pollen (particularly alder at Patschke and Boriack), but frequency increases tend to begin well before (at least by the Oldest Dryas, in the European chronology) and persist long after the time limits of the Younger Dryas.

The River Spur Site (41 VT 112)

This archeological site was investigated by the Office of the State Archaeologist in 1993 (Cloud *et al*. 1994) and by the 1995 Field School of the Department of Anthropology, University of Texas at Austin (Thomas R. Hester and Michael B. Collins, principal investigators). Buried in the five-meter terrace of the Guadalupe River in the Victoria municipal park, the sediments here apparently record a relatively well-drained floodplain (either of a small tributary stream or of the river itself) succeeded by obstruction of the drainage and the development of an oxbow lake that dried seasonally and gradually infilled by sedimentation. A fairly good microsnail fauna (Brown 1997) and some microvertebrates (well-preserved but spotty in distribution) were recovered. Bulk sediment samples were collected for radiocarbon assay, but none have been submitted. The site has no chronological control, although the basal deposits are believed to be Late Paleoindian in age, based on cultural material recovered, and presumably are about the same age as the top of the bench deposits at Berger Bluff. The snail fauna appears to respond chiefly to habitat succession at the site, rather than to regional environmental changes.

The Armstrong Site (41 CW 54)

This site, located on the San Marcos River in Caldwell County, has radiocarbon assays extending from 2400±60 RCYBP to 9160±40 RCYBP (Schroeder 2002:47; Appendix H), and the oldest assayed deposits probably overlap slightly with the most recent bench deposits at Berger Bluff. Magnetic susceptibility, carbon and nitrogen isotope, diatom, phytolith, pollen, plant macrofossil, freshwater mussel, and vertebrate studies were done Schroeder 2002, Schroeder and Oksanen 2002), but none of the data illuminate early Holocene environmental change very well, nor do they reveal much about the abruptness or magnitude of climatic change at the transition to the Holocene. The most informative data perhaps come from pollen and vertebrates. The oldest pollen (and carbon isotope) samples were collected from paleochannel fill and include pine and *Artemesia* pollen (Schroeder 1999) that I suspect represents long-distance transport from the Edwards Plateau. There are also freshwater sponge spicules in the sediments (Schroeder 2002:149). Vertebrates include muskrat and (tentatively*) Bison antiquus*, but no microvertebrates except *Geomys bursarius*.

The Richard Beene Site (41 BX 831)

The Richard Beene site is an archeological site located south of San Antonio on the Medina River, a tributary of the San Antonio River; it has supplied some paleoenvironmental data (chiefly mollusks, carbonized plant remains, and sediments). Charred bois d'arc wood (Dering and Bryant 1992, but not listed in their Table 2) was recovered from deposits dated 8805±75 and 8640±60 RCYBP (^{13}C adjusted charcoal; Alston Thoms, personal communication).

The snail data pertain mainly to habitat succession. Snail samples 25-31 were collected from soils 6, 7, and 8, which have assays ranging from 12,745±190 RCYBP

(charcoal) to 15,270±170 RCYBP (bulk carbon in sediments, which here generally dates about 1000 years older than charcoal; Alston Thoms, personal communication) and consist almost entirely of *Deroceras* slug plates, indicating a marsh or cienega habitat.

An overlying and more recent set of samples (18-23) comes from the C horizon below the Elm Creek paleosol, and from the Perez paleosol, which has dates ranging from 8805±75 RCYBP (charcoal) to 10,130±120 RCYBP (bulk carbon, soil parent material; Alston Thoms, personal communication), suggesting these deposits are contemporaneous with part of the bench deposits at Berger Bluff. This mollusk assemblage includes *Gyraulus parvus*, *Cincinnatia cincinnatiensis*, *Helisoma anceps*, *Succinea solastra*, and *Rabdotus mooreanus*, and indicates

> an open savannah with scattered woody vegetation and substantial grass cover. The periodic moist conditions, often followed by rapid desiccation would seem to indicate the occurrence of periodic alluvial input with flood debris. Local precipitation would seem to be low to moderate and, possibly seasonal in occurrence (Neck 1992).

Deposits (capped by the Medina and Elm Creek paleosols) above these levels suggest midgrass prairie and date from the middle or possibly early Holocene. Delta ^{13}C values measured for soil carbon in these paleosols suggest elevated temperatures and higher proportions of C4 plants at 11,000-10,000 RCYBP and 6000-4800 RCYBP (Nordt *et al*. 2002:Fig. 3). This timing of events for the carbon isotope sequence does not agree very well with the few values for the Berger Bluff deposits. Applewhite $\delta\ ^{13}C$ values during the period 8500-11,000 RCYBP mostly vary from about -19.9 to 21.0 and form a fairly tight cluster, although there is one value of -22.4 at 9200 RCYBP (Alston Thoms, personal communication). Nordt *et al.* (2002) interpret the less negative ^{13}C values during the estimated Younger Dryas part of the profile (the section between about 8800 and

12,700 RCYBP is undated) as an indicator of an increase in the proportion of C4 plant cover, and hence locally higher temperatures during the Younger Dryas. This conflicts with the evidence from higher latitudes, and since the site is in a riparian corridor, it is not clear why the spike toward less negative values could not as easily be due to reduction in riparian tree cover, since trees are C3 plants. At present, the Medina River channel near the site is lined with cypress trees, all of which are C3 plants. Reduction in tree cover could have derived from flood events, for example (floods on the Guadalupe River in recent years have removed many cypress trees). Annual grasses are customarily thought to have much more influence on soil isotope ratios than perennial trees, but this might not necessarily be true in closed canopy riparian corridors. Another possibility is that the interpolated age of the Perez paleosol is in error. It is worth noting that a small negative spike in C4 plant cover at the top of the Elm Creek paleosol appears to correspond well to the 8200 cal BP event (see Nordt *et al.* 2002:Fig. 3). In this case, the known climate event and the direction of isotope change appear to be in agreement.

Winston's Cave (Bexar County)

Radiocarbon assays from bulk sediment (n = 9) in this sinkhole on Camp Bullis are somewhat problematical and are offset somewhat from the two charcoal assays (Hudler 2000:Table 4-13). The oldest date on sediment is 10,790±80 RCYBP, and the proposed age-depth model for the site estimates the age range of the matrix column at 6270-10,790 RCYBP. If the assays and age modeling are correct, the section likely includes all of the Younger Dryas. Excavation was done in 5 cm levels. Pollen (analyzed by John Jones), snail (analyzed by Richard Fullington), vertebrate (analyzed by David Froelich), and magnetic susceptibility data are available. The snails include 11 terrestrial taxa and one aquatic species (a single example of an extirpated Pleistocene species from

level 50). The base of the column (levels 32-54) shows greater species richness, and according to Fullington, there is some indication of aridification from level 28 up to the surface of the deposits (Hudler 2000:81). The pollen samples are somewhat poorly preserved, but include small amounts of sweetgum pollen (Hudler 2000:Fig. 4-19). There are no pollen data before about 9900 RCYBP (estimated date; Hudler 2000:70). The magnetic susceptibility samples show a trend of increasing low-frequency values from the Younger Dryas right through the middle Holocene. Taken at face value, this should imply increasing environmental moisture, which is contrary to expectations.

Friesenhahn Cave (41 BX 177, Bexar County)

Friesenhahn Cave is located at the eastern edge of the Edwards Plateau, at an elevation of about 349 m (1145 ft), not far from the Balcones Escarpment; it has some scattered cultural material around the entrance (hence the trinomial designation), but is chiefly a paleontological site. This sinkhole was extensively excavated by the Texas Memorial Museum in 1949 and 1951 (Evans 1961), and additional excavations were done by Graham 1976) in the 1970s. Graham excavated in 10 cm levels but describes the stratigraphy in natural depositional units. He also collected pollen samples, seven of which were processed by Stephen A. Hall, with the results eventually published much later by Hall and Valastro (1995). Interpretation of this site is rendered difficult because all three investigators use different systems of stratigraphic nomenclature. Graham provides a reconciliation of his and Evans's systems (Graham 1976:Table 1), but Hall gives no explanation. Judging by the sediment descriptions, apparently Hall's "gray clay" equals Graham's units 2B and 3A, his "red clay" equals Graham's unit 3B (and 3C?), his "red fill" perhaps equals Graham's units 3D (?) and 2F, and his "black fill" must equal

Graham's unit 2G. Graham wet-screened his sediments through 1/16-inch mesh, but the collection method for the TMM party is not specified.

This site has good pollen and vertebrate data, but unfortunately age control is very poor. Apparently, there are at least 12 radiocarbon assays. Ten of these are reported by Graham (1976:Table 2) and have been critiqued for reliability by Toomey (1993:Table 2). Another assay (Tx-1768, 19,880±430 RCYBP) comes from "the middle of the sequence." The University of Texas Radiocarbon Laboratory ran separate assays on apatite, collagen (and in one case, dentine) fractions from mammoth and rodent bone from units 3A, 3B, 3C, and 2C. Unfortunately, the collagen content was so small that very large standard errors (as much as ±4340 years) resulted, and there are major discrepancies between the apatite and collagen fractions. In two cases the collagen fraction is older, and in two others the apatite is older. The dates are probably sufficient to indicate that units 3A and 3B are likely Full Glacial in age, but the assays for units 3C and 2C are so wildly variable that I consider them of unknown age. Graham assigns them a post 10,000 BP age (Graham 1976:29), although mammoth bone (assayed at 4890 and 9640 BP) is present, and mammoth is not normally considered to have survived into the Holocene here.

Certainly, the age control at this site is inadequate to allow us to identify the Pleistocene-Holocene boundary, measure its abruptness, or even discern whether it is preserved here, nor can we learn anything about the presence or absence of a Younger Dryas signal. It seems likely that the earliest units, at least (Zone 1, units 2A, 2B, 3A, and 3B) predate the bench deposits at Berger Bluff. Graham (1976:221) proposes that the

cave was sealed and did not receive sediments from 12,000 to 10,000 RCYBP, but I think the dating is too questionable even to establish that with any certainty.

Friesenhahn Cave contains a number of extinct [mammoth, mastodon, tapir, peccaries, horse, bison, camel, dire wolf, shortfaced bear, sabertoothed cats, tortoises (*Geochelone wilsoni*), box turtle hybrid (*Terrapene carolina putnami* X *T. c. triunguis*), toad (*Bufo woodhousei bexarensis*)] and extralimital (short-tailed shrew, southern bog lemming, cotton mouse, cactus mouse, eastern chipmunk, and perhaps pine or prairie vole) vertebrate taxa (Graham 1976; Holman 1969; Martin 1968; Preston 1979). All of the extralimital species are ones that are now found to the east and/or north, in wetter or cooler climates. The best example is perhaps the eastern chipmunk (*Tamias striatus*). Graham (1984) calculated these indicate summers either 7.5° C cooler and 120 mm wetter than today, or else 300 mm wetter, if temperatures were the same as today. However, Toomey (1993:24) suggests an increase of only 10 mm/month in November-March would enable these chipmunks to survive in Central Texas, or 15 mm in June and 30 mm of additional precipitation in July.

Hall recovered small amounts of spruce pollen from the "gray clay" unit, which is consistent with a Full Glacial of possibly Late Glacial age (and the assays of 14,020 and 19,600 RCYBP). The "gray clay" and "red clay" also contained fairly abundant pinyon pine pollen and little oak pollen. Small amounts of sweetgum pollen were found in the "gray clay" and the modern "black fill" (Hall and Valastro 1995). Hall concludes that the

> ...Edwards Plateau had less tree pollen (*Pinus, Juniperus, Quercus*) than modern shortgrass and tallgrass prairies, although the Edwards Plateau may have had small populations of pinyon pine and deciduous taxa (hickory, ash, elm, walnut, alder, liquidambar) in riparian and canyon habitats.... Given a more equable but

> cooler and moister climate, as indicated by mammalian faunas in the southern Great Plains, the glacial-age herbaceous prairie communities may have been composed of some assortment of species that differ from present-day prairie floras (hall and Valastro 1995:243-244).

Hall's Cave (= Klein Cave, 41 KR 474, Kerr County)

Hall's Cave, formerly known as Klein Cave, is located on the high surface of the Edwards Plateau at 677 m (2220 ft) above sea level, at the head of the Guadalupe River basin. In fact, the divide marking the head of the basin lies only about a kilometer farther to the northwest. Because of its elevation and distance from the Gulf, this locality is somewhat cooler and less influenced by Gulf moisture than Berger Bluff, and it would not be surprising to find it has a somewhat different paleoenvironmental story to tell. At present, the Gulf shoreline lies about 358 km down-basin, and at the Wisconsinan lowstand, would have been about 446 km away. Excavations were done by Roth (1972) in 1966-68; by a geologist, Collins, in 1968-70; and by Toomey (1993) beginning in 1986. This is another site which, like Friesenhahn Cave, has both vertebrate fauna and pollen preserved. There is an extensive series of radiocarbon assays (Collins 1995:379), most of which (like the pollen analysis) remain unpublished. A snail fauna was recovered, but it also remains unpublished. Some carbon isotope findings (Toomey, Huebner, and Boutton 1992) have been published. Toomey excavated, for the most part, in 5 cm levels and washed the matrix through nested 2.5 mm and 1.2 mm screens. From the initial set of radiocarbon assays, it appears that the stratigraphy is somewhat compressed below about 8000 RCYBP (this is most easily seen in Toomey 1993:Fig. 40), which means that time resolution in the basal section is perhaps roughly 500 years per 5 cm excavation level.

The Hall's Cave data suggest significant warming by the Oldest Dryas/Bolling intervals (14,500-12,500 RCYBP, probably with open grassland present), with continued warming to about 11,500 RCYBP, with temperatures close to modern after that (Toomey 1993:448). There is no detectable Younger Dryas temperature signal. A moisture signal beginning at 13,500 RCYBP is provided by the ratio of desert shrews, *Notiosorex*, to least shrews, *Cryptotis*. This suggests increasing aridity from 12,300-10,400 RCYBP (parts of the Bolling, Older Dryas, Allerod, and Younger Dryas), with a return to slightly wetter conditions at 10,400 RCYBP, followed by resumed aridity, peaking in the mid-Holocene (Toomey 1993:450-451. The more extensive set of assays suggests a mesic interval that corresponds fairly well to the Younger Dryas (Collins 1995:Table 2), with further aridification at about 9000 RCYBP.

The Late Glacial fauna from Hall's Cave is disharmonious. Toomey (1993:461) identifies several allopatric species pairs (*Notiosorex* crawfordi-Synaptomys cooperi, *Myotis velifer-Sorex cinereus/haydeni*, *Myotis velifer/Zapus hudsonius*) that suggest mild winters and cool summers, plus gopher tortoises *(Geochelone wilsoni*) and extinct roadrunners (*Geococcyx californianus conklingi*) that suggest much the same thing.

Other sites

Studies of speleothems in various caves in the Guadalupe River basin indicate the late glacial period was wetter than present, but there are too few uranium-thorium dated speleothems to detail the climatic chronology.

> However, water levels at least 7 m higher than the present did occur throughout most of the Lower Glen Rose in the Guadalupe River basin during the Late Pleistocene based on levels of resolutioned speleothems (the TB stalactite was more than 10 m above modern base level). Recent calcite deposition has hidden most of the resolution that occurred in Cave Without a Name, but extensive

> canopies and other unusually-shaped speleothems (e.g., the "Bomb Burst") are indicative of a Guadalupe River basin water table at least 7 m higher than its current elevation. In the Cibolo Creek basin, excellent examples of resolutioned speleothems in Cascade Caverns and other caves prove the water table was more than 20 m above its current elevation (Veni 1997:265).

A single humate date (7300±190 RCYBP, $\delta\ ^{13}C$ is -15‰) from Camp Pearl Wheat, in Kerr County pertains to a period of fine-grained deposition, with savanna habitat inferred (Collins *et al.* 1990:92), but is too recent to record the transition to the Holocene.

GLACIAL-AGE CALICHE AND OTHER RECORDS IN DEEP SOUTH TEXAS

There are a few south Texas paleoenvironmental sites that are far too old to be comparable to Berger Bluff, but nevertheless interesting because they hint at either arid or mesic conditions during the late Pleistocene. These include a number of sites with carbonate that is ostensibly pedogenic in origin and ostensibly Full Glacial or Late Glacial in age. Some of these are rather puzzling. The first is an exposure of "caliche" (presumably a pedogenic soil carbonate horizon) six miles west of Karnes City, and about 30 km southwest of the southwestern boundary of the Berger Bluff catchment. A series of seven radiocarbon assays on both massive caliche and caliche joint fills ranges from 13,750±230 to 20,310±430 RCYBP uncal, but the joint fills are more variable in age and may incorporate carbonate from bedrock. Three assays on the massive variety average 17,470 RCYBP, suggesting seasonally arid conditions during the Full Glacial (Valastro and Davis 1970:623-624). No $\delta\ ^{13}C$ determinations are reported. This location is at N 28° 52' 31" which is close to the latitude of Berger Bluff. This record is problematical in view

of the indications of greater effective moisture and reduced seasonality in the Late Glacial period that were discussed in Chapter 1.

McBride and Honda (1994) studied *in situ* beachrock, beach clasts, and clasts in Intracoastal Waterway spoil piles from Padre Island and the Laguna Madre (Cameron County north to Nueces County). Two-thirds of the samples they studied showed evidence of calichification, and radiocarbon assays ranged from 18,300 to 27,250 RCYBP uncal. They conclude that "this was a time of low sea level during the late Pleistocene and a feasible time for calichification. Nevertheless, the dates should be viewed with skepticism" (McBride and Honda 1994:470). Other samples of marine limestone, sandstone, or shelly sandstone produced assays of 13,200, 30,900, and 38,000 RCYBP, and the authors suggest that at these dates, sea level was far below the level of the samples, indicating that the assays are spuriously recent (but see below). The $\delta\ ^{13}C$ values for the calichified samples vary widely and range from -0.5 to -8.4, with an average somewhere near -4.0 ‰ (McBride and Honda 1994:Table 1).

Prouty (1996) studied outcrops of coquina with karst features (solution pipes and laminated crusts) along the west shore of the Laguna Madre just south of Baffin Bay, in Kenedy County. The coquina includes open Gulf and bay-type mollusks but is now exposed subaerially. It has radiocarbon assays ranging from 25,750 to 32,370 RCYBP (Prouty 1996:Table 1). Again, as in the previous case, sea level at that time would have been much lower. Prouty offers two possible explanations, neither particularly convincing: 1) contamination by younger carbon, or 2) enhanced levels of radiocarbon due to a cosmic flux event at 60,000 BP. The laminated caliche crusts occur on the coquina, and the solution pipes penetrate it, some of them extending below present sea level. She suggests that

> During the glacial advance the regional climate was wetter than today, promoting karstification. Solution pipes probably originated through leaching of the limestone bedrock associated with plant respiration, perhaps concentrated in local soil pockets occupying depressions on the coquina surface....With the commencement of the Holocene...the climate of south Texas gradually became drier. Regional precipitation diminished, and karstification of the coquina finally ceased about 7000 yr B.P. (Prouty 1996:350).

Assays on the crusts range from 7720±90 RCYBP to 16,450±210 RCYBP uncal (Table 2.5), and in all three cases where upper and lower crust layers were assayed separately, the underlying layers are older. As can been seen, these range from the late Full Glacial, through the Younger Dryas, into the early Holocene. Prouty suggests that the crusts are formed partly from carbonate mobilized from the coquina, and partly from carbon of atmospheric origin, so that the true ages are younger than the assays. The $\delta\ ^{13}C$ values for the crusts range from -2.1 to -8.0 ‰, and average about -5.0 ‰.

Another possible example of calichification is found in 14 m of Gulf water, 3.2 km offshore from Padre Island, south of Baffin Bay (Thayer, La Rocque, and Tunnell 1974). This is a former freshwater lake bed, now submerged, that has filled with sediments and carbonate and exists as inverted topography on the seafloor. It is undated but has Columbian mammoth, mastodon, and bison remains as well as land snails and freshwater aquatic snails (*Planorbella trivolvis* and *Physa* sp.) and presumably existed as a seasonal lake on part of the shelf exposed by the Late Pleistocene sea level drop. The sediments apparently contain both marl and carbonate redistributed by pedogenic processes.

Table 2.5. Radiocarbon Assays for South Texas Paleoenvironmental Sites.

Assays on laminated carbonate crusts, Laguna Madre, Kenedy County (source, Prouty 1996:Table 1)

Tx-7956	7720±90 RCYBP uncal	
Tx-7647a	8220±160 RCYBP uncal	
Tx-7957	9020±100 RCYBP uncal	
Tx-7651	10,720±180 RCYBP uncal	
Tx-7961	10,880±100 RCYBP uncal	
Tx-7650	11,060±150 RCYBP uncal	
Tx-7959	12,370±120 RCYBP uncal	
Tx-7960	14,530±170 RCYBP uncal	
Tx-7962	16,450±210 RCYBP uncal	

Assays on bone (mammoth and unidentified) La Paloma Mammoth Site, Kenedy County (source, Suhm 1980:98)

Tx-2197	8080±480 RCYBP uncal	enamel
Tx-2195	9250±2280 RCYBP uncal	unidentified collagen
Tx-2197	9380±4690 RCYBP uncal	dentine
Tx-2195	9560±120 RCYBP uncal	unidentified apatite
Tx-2196	9830±110 RCYBP uncal	collagen

Inland to the west of this location is a pair of sites, La Paloma Mammoth site (41 KN 17) and Indian Hill (41 KN 18) situated along Palo Blanco Creek near the western border of Kenedy County. Suhm (1980:79) lists the trinomial designation for La Paloma as "41 KN 78" (*sic*), but that is erroneous. La Paloma Mammoth Site consists of bones of Columbian mammoth, mastodon, horse, *Bison antiquus*, ground sloth, and unidentified snakes, fish, and amphibians (plus crab remains) discovered in place in clay-rich alluvial sand associated with Palo Blanco Creek, which according to Suhm is the dry, underfit remnant of a larger Late Pleistocene stream. Deer antler and glyptodon scutes were also recovered from the backfill. Indian Hill is a much smaller isolated site located to the east,

and well to the north of the Palo Blanco channel. Raymond Neck (1981) studied snails from both sites, finding aquatic snails (*Planorbella trivolvis*, *Biomphalaria havanensis*, and *Physa [Physella] virgata*, all of which are found at Berger Bluff as well) at La Paloma only. Neck concluded that these taxa, along with the crab ossicles, indicated the presence of stagnant, brackish water. Certainly the fish, amphibians, and grazing animals seem to indicate a period with somewhat greater soil moisture and runoff than at present. There is at least one paleosol and some evidence of calichification in the alluvial sediments overlying the bone bed (Suhm 1980:90). Farther upstream along Palo Blanco Creek, about 24 km west of Falfurrias, Hubricht reported "large numbers of freshwater [snail] shells of northern species such as *Valvata tricarinata* (Say)....The aquatic species, most of which are species of permanent bodies of water, would also indicate that the climate was much wetter than at present" (Hubricht 1962:1).

A series of radiocarbon assays (Table 2.5) from bone and teeth range from 8080 RCYBP to 9830 RCYBP. Taken at face value, these would indicate an early Holocene age, but the dates are probably much too recent. Radiocarbon assays on extinct North American megafauna that are later than 10,000 RCYBP (Meltzer and Mead 1983) or in some cases perhaps even 12,000 RCYBP (Grayson 1987) are likely to be spurious, and it seems unlikely that extinct proboscideans would survive as late as 8000 or 9000 BP on the Rio Grande alluvial plain. One mammoth bone fragment (Tx-2195) retained enough collagen for a conventional assay, although not a useful one. In summary, this site hints at somewhat higher levels of effective moisture, but for the time being its age must be regarded as essentially unknown.

The Petronila Creek site (41 NU 246) located near Driscoll, in Nueces County (Fig. 1.26), has a fairly extensive set of radiocarbon assays (Lewis 1988, 1996; Johnson 1993). A buried stratum of fine sand with an extensive Rancholabrean fauna has assays that are Full Glacial in age (18,180±330 RCYBP on *Mammuthus jeffersoni* apatite, 17,190±400 and 16,880±380 RCYBP on organics bound to clays immediately overlying the sand stratum. In some areas there are pea-sized caliche nodules or sheets of caliche in the sand, and seams and nodules of caliche also occur in the overlying clay-rich strata.

Bob Lewis (personal communication) believes that present Petronila Creek is also underfit in comparison to its Full Glacial discharge, and the fauna includes a good many aquatic or riparian taxa: muskrat (?), alligator, pond and softshell turtles, frogs, salamanders, fish (including large gar), freshwater mussels, and aquatic snails (Lewis 1996:Table 1). These (especially the alligator and very large gar) indicate a significant and reliable water source. At the same time, there are many taxa (mammoth, *Bison antiquus*, horse, *Capromeryx*, black-tailed prairie dog, jackrabbit, plus saltbush seeds) that indicate grasslands on the surrounding Beaumont prairie surface. There are well over 200 prairie dog teeth alone. Johnson (1993:106) interprets the small mammal fauna as representative of a shortgrass prairie, although the riparian taxa seem to suggest greater effective moisture.

CONCLUSIONS

1. Significant radiocarbon plateaux are present during the estimated span of accumulation of the bench deposits, at 10,400, 10,000, and 9600-9500 RCYBP uncal, but most of

the radiocarbon assays from Berger Bluff fall between these plateaux. Only one of the assays falls in the 10,000 BP plateau.

2. The Younger Dryas, an important episode of climatic cooling that lasted 800 years, from about 10,897-10,091 RCYBP uncal (usually rounded off to 11-10 K), is best known from the North Atlantic region. It also occurs elsewhere in the world, but in patchy fashion. It is not yet clear whether its occurrence was truly mosaic in nature, or if the gaps are simply due to poor records. Much of the newest evidence suggests it was a global event. The Younger Dryas is followed in the Preboreal and Boreal by a few other less well defined cooling events, about which even less is known.

3. The evidence for a Younger Dryas climatic signal in the Guadalupe and San Antonio river basins is equivocal. Some of the pollen types (mostly notably birch and sedge) at Hershop Bog show a response that is probably moisture-related at about the correct time, if the age-depth model I have used is correct. However, I have only qualified confidence in the age model because of the sampling interval and the frequent discrepancies between bulk peat assays that have been found in other bogs. A possible mesic period at about the same time at Hall's Cave may also represent the Younger Dryas. Some of the pollen types that peak during the Younger Dryas actually show increases that anticipate its start and persist after the end of the period, as defined in the North Atlantic, a pattern that parallels the history of spring-related "black mats" in the Great Basin (Quade *et al*. 1998).

4. Other sites in the basins either lack a good regional climatic signal or have insufficient time resolution. None of them have the resolution or specificity necessary to address

the questions of abruptness and degree of climatic change posed by the Greenland summit ice cores (as discussed in Chapter 1).

5. The best and most consistent data sets for evaluating postglacial sea level in the Gulf come from coral reefs at Tahiti, Barbados, and the Huon Peninsula of New Guinea. For the most part, these do not allow recognition of possible stillstands or regressions, but they do a good job of portraying the main trend of sea level rise (Table 2.2), and provide the basis for making some crude calculations of postglacial channel gradients for Coleto Creek and the Guadalupe River.

6. Gradient calculations suggest that rising sea level caused coastal stream gradients to diminish steadily, despite the lengthening of the channels that occurred during lowstands (Table 2.3). Gradients may have been locally heterogeneous, however, and adjustments to sea level may have lagged drastically, showing *complex responses* (*sensu* Schumm 1977).

7. Evidence from high-resolution cores on the Louisiana continental shelf suggests there were at least five major meltwater episodes, or Mississippi superfloods, during deglaciation. The result of Bolling-Alleröd warming, four of these occurred before the Younger Dryas, the largest two peaking at 13,380 RCYBP and 11,900 RCYBP, and flooding ceased during the Younger Dryas cold spell. The last episode was actually a cluster of four discrete floods between 9970 and 8900 RCYBP produced by peaking summer insolation, and although these events were only about half the magnitude of the largest superfloods, they may have had a major impact on regional climate by continuing to introduce frigid meltwater into the Gulf during a period when insolation

was peaking, and possibly limiting warm-season sea surface temperatures below the level necessary for hurricane formation. Land-sea thermal contrasts were also probably at a maximum during this period, and this must have affected regional climate as well. It may seem paradoxical, but the two periods of greatest warming over the Laurentide ice sheet (the Bolling-Alleröd interval preceding the Younger Dryas, and the early Holocene following it) were the periods when meltwater release through the Mississippi probably created regional cooling in the Gulf of Mexico, with the episodic nature of the cooling episodes due to blocking and unblocking of different Lake Agassiz outlets.

8. Hurricanes form in the Gulf when a water temperature of 26° C is sustained for several months, and usually extends to a depth of 60 m, and when *El Niño*-directed winds aloft are not available to shear off the tops of the developing cyclones. At present, July-October are the paramount months for hurricane development.

9. Despite all the research that has been done, we cannot specify when average summer water temperatures reached 26° C. It was likely in the early Holocene, probably after pulse IB (=MWF5), and perhaps somewhat after 9000 RCYBP. The earliest possible geologic evidence for major storm events in the eastern Gulf seems to be before 8000 RCYBP. Alkenone paleothermometry and further foraminiferal studies hold great promise for solving this question, but they must be supported by close-interval AMS dating of the marine cores.

10. August and September insolation did not peak until after 8000 RCYBP (Figure 1.4). This, plus persistent meltwater from MWF5 (Aharon 2003), suggests hurricanes were

absent from the Gulf of Mexico until the early Holocene (perhaps somewhere in the span 8000-9800 RCYBP), but early Holocene hurricanes, once they began, may have been more severe than contemporary examples because of greater insolation.

11. There are some records from south Texas that imply aridity during the Full Glacial. Calichification, for example, is usually taken to imply climates that are at least seasonally warm and have seasonally distributed rainfall. These records are too early to be of direct concern here, but they might seem to imply the model of storm-track displacement and equable rainfall presented in Chapter 1 is invalid. Because most of these records are well to the south of N 30° latitude, and because the full age span of most of them is not known, I do not think the model is invalidated.

12. Trees that are today confined to the wetter region of east Texas may have been more widespread in south Texas in the past. Very small amounts of sweetgum (*Liquidambar*) pollen — typically one or two grains in a single sample — show up in early contexts at many of the sites considered here, such as South Soefje bog, Hershop Bog, Winston's Cave, Friesenhahn Cave, as well as in the Leon Creek paleosol at the Richard Beene site (Dering and Bryant 1992). It also shows up in sample 19 at the Devil's Mouth site, dating sometime after 8780±310 RCYBP (Bryant and Larson 1968). Some of the alluvial or colluvial contexts might be due to reworking of Pleistocene pollen, but I suspect sweetgum was actually present as a very minor component of floodplain forests in south Texas well into the Holocene. Likewise, birch may have been much more widespread than is generally perceived. Hazelnut shows up in several levels at South Soefje Bog. The case for loblolly pine is ambiguous, but as I mentioned in Chapter 1, its anthropogenic redistribution on sandy

Miocene bedrock in the study area seems to hint it could have been more widespread in the past. Alder, birch, sweetgum and loblolly pine are all typical southeastern US tree species today.

13. Both pollen and faunal records from the Guadalupe and San Antonio River basins hint at greater species richness during the Late Pleistocene. Not only were floras and faunas disharmonious, they were also more diverse. Some of this diversity probably lingered on into the early Holocene in protected habitats such as escarpments and riparian corridors. The evidence for this at Berger Bluff will unfold as the chapters on various biotic fossils are presented.

14. If there is a unifying theme for the proxy records reviewed in this chapter, it is poor age control. Except for recently excavated sites, such as Richard Beene and Hall's Cave, which have better sampling resolution and significant AMS radiocarbon control, the record is poorly resolved. Marine cores, peat bogs, caliche deposits, paleontological sites, and sea level indicators all suffer from lack of AMS dating and ambiguous assays.

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Chapter 3: Excavation and Analysis Methods

INTRODUCTION

The chief purpose of this chapter is to provide an overview of the excavation methods and of the provenience units from which different kinds of samples were drawn. The actual details of analysis for the various classes of data will be found in their respective chapters or appendices.

Fieldwork objectives: how they structured results

It is important to understand that the original objective of excavation in the bench deposits was simply to assess the extent and significance of cultural remains buried in the bench sediments. This was explicitly stated in the contract amendment under which the UTSA-CAR crew was dispatched to the site in November, 1979. The contract was for three weeks of field investigation with a four-person crew. The initial arrangement with the Guadalupe-Blanco River Authority actually stated that the CAR was to provide a statement in advance of "expected findings" and that if these were not met after one week, the remaining two weeks of investigation were to be cancelled (letter of October 23, 1979, John H. Specht to Thomas R. Hester). This arrangement was later modified to allow the project to run its full extent. About 22 days were spent in the field with varying numbers of paid crew members, and I spent about another two weeks at the site alone or with volunteer workers. Although the bench excavations were a separate project from the main block excavations that took place the preceding summer, I strove to maintain continuity in the grid and elevation systems, feature numbering, and film roll numbering.

The paleoenvironmental emphasis of the present study is almost *entirely post hoc*, and is possible only because the standard archeological field practice of the time included accurate profiling of vertical exposures and generous collection of matrix samples. Many of the analyses that have been done were not yet envisioned when the samples were collected in the field. The original budget allowed for radiocarbon assays and phytolith analysis, plus very limited funds for a field geologist, faunal analysis, soil analysis, and malacological analysis.

However, it is important to recognize that because the original rationale of the project was not explicitly paleoenvironmental in nature, some important pieces of information were never collected. In general, our view of the bench sediments was too spatially restricted. There are two key areas where this was the case. In subsequent chapters, I will argue that the most important visible environmental change in the early history of Berger Bluff is the dramatic change in depositional style at the top of the bench deposits. Unfortunately, in large part because the contract specified that we investigate only the bench sediments, I have no samples that span this important transition. We know a great deal now about what preceded this transition, but can infer only from visual observation of the bluff what came after.

A second example pertains to the nature of the banded sediments visible in the cutbank. In order to evaluate their origin, we need to know how laterally extensive they are. Backhoe trenching on the opposite side of the valley, in the vicinity of 41 VT 49-51, might have helped to clarify this matter, but was clearly beyond the scope of the contract. In lieu of this, we can rely only on the cutbank exposures downvalley from the bench area. Put more succinctly, an explicitly geoarcheological approach to the bench

excavations, had circumstances allowed it, would have examined a much wider area, both horizontally and vertically.

An explicitly geoarcheological approach would also probably have included some oriented sediment samples for micromorphological sectioning. During the fieldwork, I considered collecting a profile monolith, but did not have the necessary supplies on hand, and did not do so. Un-oriented micromorphological samples were later extracted from bags of loose matrix, and these have proved very informative, but oriented samples would have been even more useful.

Despite the *post hoc* reorientation of the present study, the site remains one of the most important sources of paleoenvironmental data on the central part of the Texas coastal plain. Archeological sites are customarily regarded as poor sources of environmental indicators because humans tend to modify their microhabitats extensively, but it is clear from the archeological evidence that humans had very limited impact on the site until much later in the Holocene. The earliest uses of the site were essentially non-residential, and it is not until the late Holocene that occupation density and frequency increased to the point that anthropogenic modification of the deposits became pronounced.

FIELD METHODS

Grid system

Excavation began with an arbitrary grid system and arbitrary elevation datum (designated 100.00 meters) already established by David Brown for his blufftop

excavations in the summer of 1979. This grid was projected onto the bench before excavation was begun, and a secondary datum was also set up at the northwest end of the bench. A transit was set up over the northeast corner stake (N103/E100) of the blufftop excavation block, and was aligned on the southeast corner stake; grid north was found to lie at N 4° 39' W, or slightly to the west of magnetic north. This grid north was retained for the bench project. A north-south E100 grid line was laid out on the sloping bench surface, and a known point (N105) on this line was plumbed from the blufftop. The rest of the grid system was projected from this point using the transit and a steel tape. The unevenly sloping bench topography made frequent use of a plumb line necessary for accurate location of grid points.

All excavation units are one-meter squares, named by the north and east coordinates of the *southwest* corner, except Unit 2, a one-meter square excavated the previous summer but not aligned with the grid.

In addition to the bench excavations, of course, Area A has the 3 x 4 m excavation block dug in the summer of 1979, plus a 2 x 2 m test pit (1A) and six shovel tests dug in 1977. Area B has a 1 x 1 m test pit and five shovel tests dug in 1977, plus four backhoe trenches dug in 1983. There are also four backhoe trenches and five shovel tests outside the recognized surface limits of areas A and B. None of these are of direct concern here.

Elevation control

The primary datum for excavations at Berger Bluff was a 60-penny nail driven by David Brown into a tree northwest of the blufftop excavation block in the summer of 1979. I would estimate it rested perhaps 50-60 cm above the ground surface, but due to

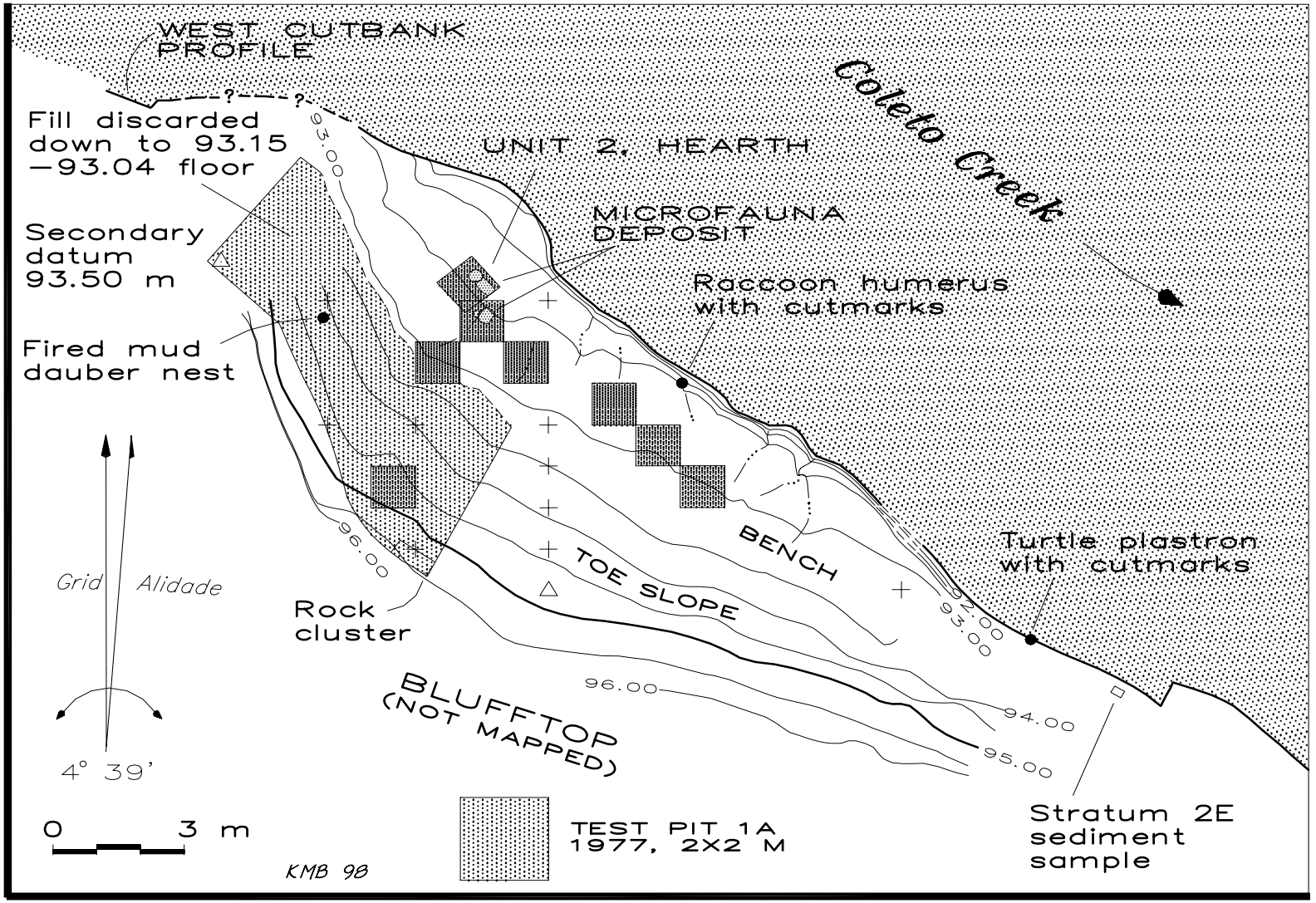
the creekward slope of the terrain, the top of this nail, assigned an arbitrary elevation of 100.00 m, was at the same elevation as the southwest corner (N97 E96) of the excavation block (D. Brown 1983:16). During that project, I measured the elevation of the hearth (Feature 5) exposed near the bench surface. Using a transit to run a combination stadia rod and steel tape traverse from the primary datum down to the exposed surface, I estimated the surface of the hearth at 92.355 m (field notes, June 29, 1979).

The primary datum has now been lost due to wave action from the reservoir. Recognizing the impending removal of the datum, on April 17, 1981, I returned to the site with Joan DeCosta and set two new datum points (steel rebar in concrete) south of the blufftop excavation block, at N90.5 E96 and N82 E96. The first of these was set at an even elevation point.

At the outset of the bench excavations, I set a secondary datum at 93.50 m (see Fig. 3.1 for location) on the bench near the upper contact of stratum 3, west of the excavations. At the time, I could not locate the primary datum, and instead I measured from a profile pin (92.50 m) near N100 E96 (field notes of November 26, 1979). A traverse was run to a temporary stake on the bluff edge west of the bench, then a steel tape was dropped six meters to set a piece of one-inch steel rebar in concrete at the appropriate elevation. When the traverse was rechecked (several times) three days later, it was found to be 14 cm in error, so it was reset, then all subsequent elevation measurements for the bench were established using the 93.50 m secondary datum. A transit recheck of the highest elevation on the surface of the hearth (Feature 5) made on December 30, 1979, gave an elevation of 92.375 m, which is in close agreement with the traverse made the previous summer. Since the instrument HI was taken from the

secondary datum, this supports the accuracy of the secondary datum. The secondary datum was used to obtain daily instrument HI readings that were used for plane table mapping, excavation level checks, and for setting profile pins.

Figure 3.1 *(following page, landscape orientation).* Contour Map of the Bench Area. Contour interval 50 cm. Blufftop area with test pit 1A is shown, but topographic mapping of the bench extended no higher than 96 m. Line of crosses marks the E100 grid line. Unit 2 and the seven excavation units dug into the bench are shown, as well as the artificial cut made along the west side of the bench. Units are identified by grid coordinates in Figure 3.2.


WEST CUTBANK PROFILE
Fill discarded down to 93.15 —93.04 floor
Secondary datum 93.50 m
Fired mud dauber nest
UNIT 2, HEARTH
MICROFAUNA DEPOSIT
Raccoon humerus with cutmarks
Coleto Creek
Turtle plastron with cutmarks
BENCH
TOE SLOPE
Rock cluster
BLUFFTOP (NOT MAPPED)
93.00
96.00
92.00
94.00
95.00
Grid
Alidade
4° 39'
0
3 m
KMB 98
TEST PIT 1A 1977, 2X2 M
Stratum 2E sediment sample

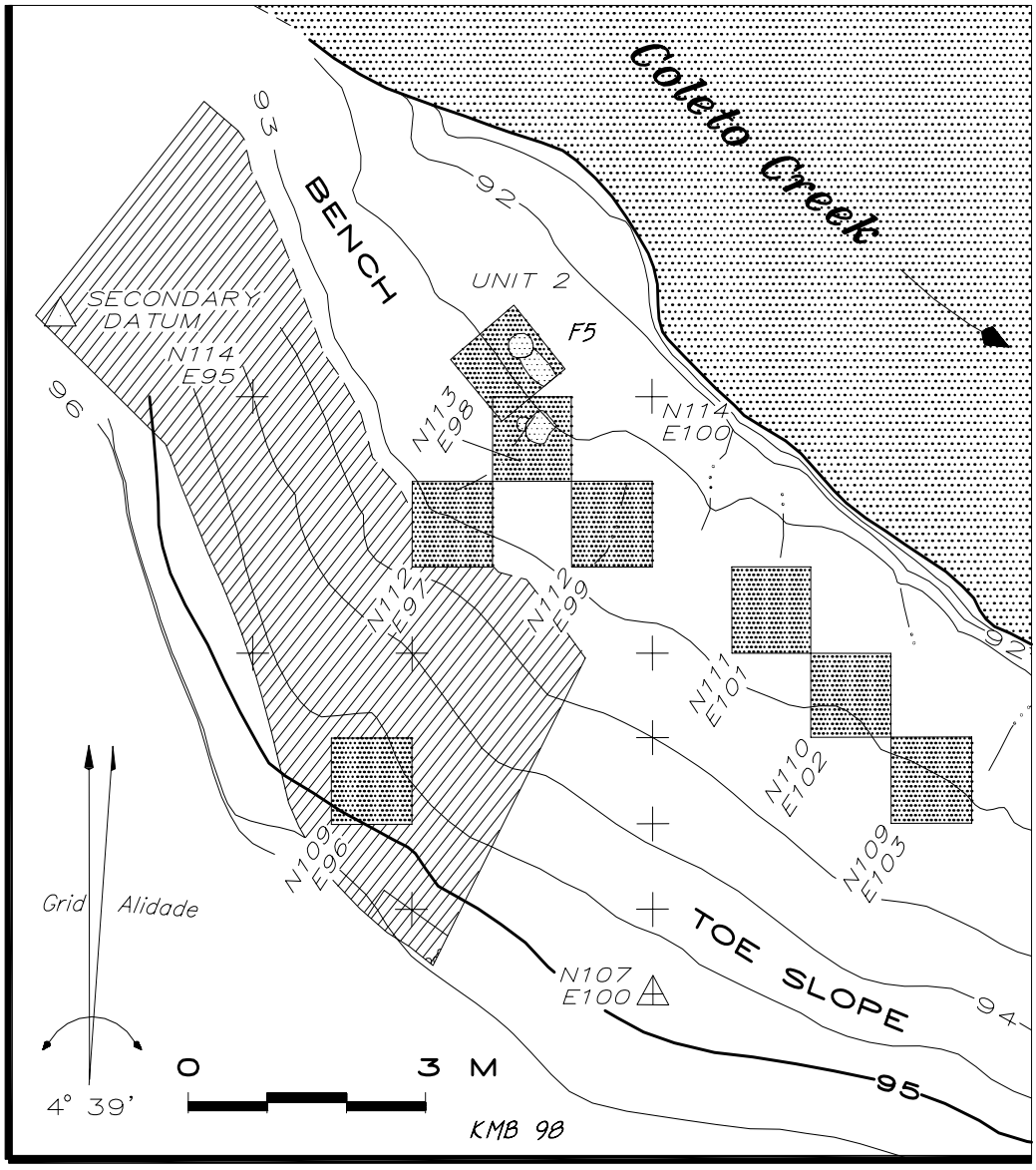


Figure 3.2. Excavation Grid Layout. Detail of excavation units in the bench area of Berger Bluff, enlarged from the preceding figure. Contour interval is 50 cm. Fill was stripped from the large hatched area to produce a flat surface from which unit N109 E96 was dug. Rectangle at base of south end of stripped area is informal unit dug to investigate rock cluster. Light-colored areas in Unit 2 and unit N113 E98 are the hearth, Feature 5, and adjacent microfauna deposit.

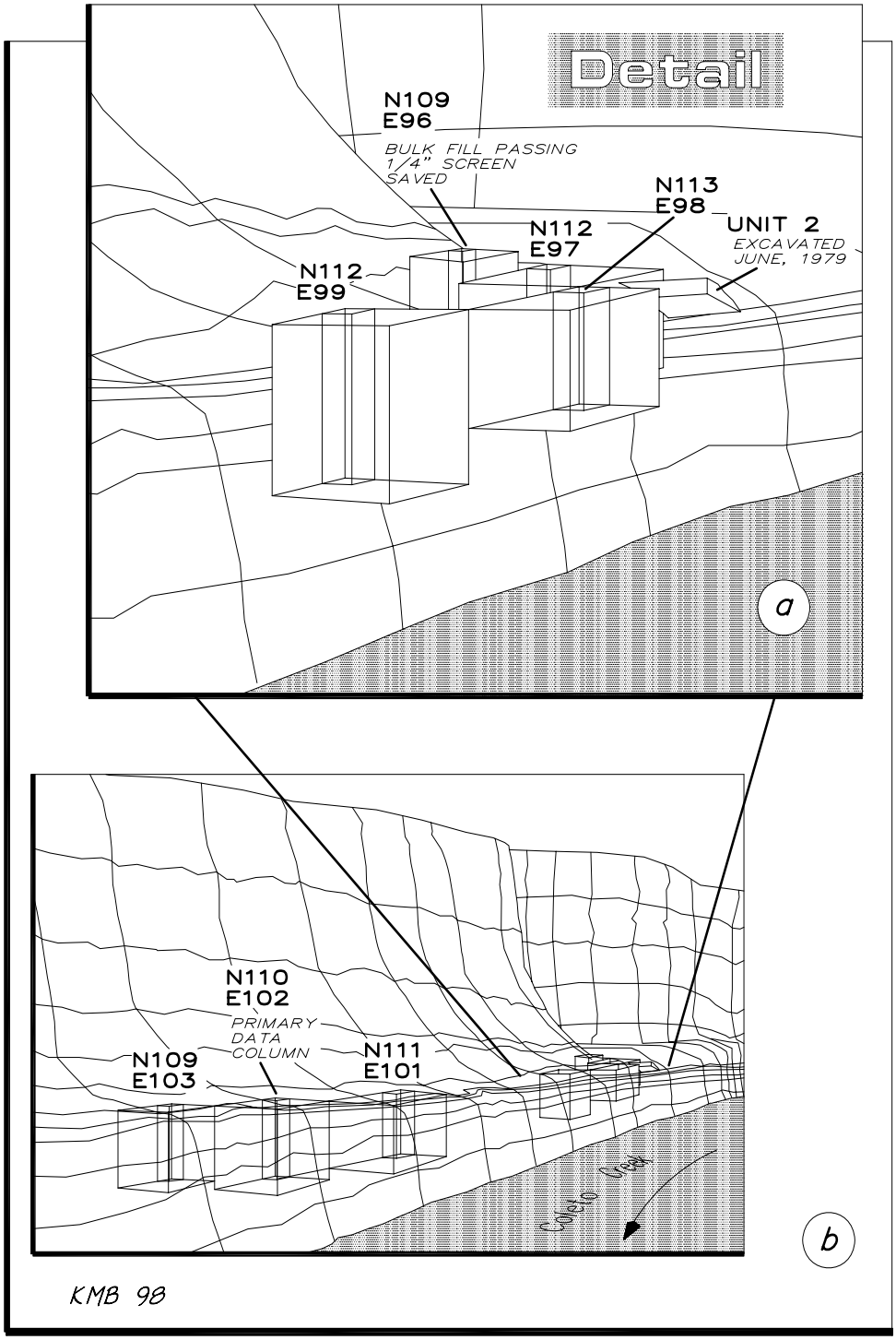


Figure 3.3. Oblique Schematic View of Excavation Units. Wireframe "topography" is pictorial only, not literal. View looking southwest.

Excavation units

Aside from the original Unit 2, seven 1 x 1 m excavation units were dug into the bench (Figs. 3.1 to 3.3, 3.5, and 3.6). Including Unit 2, these represent a total of 6.76 m^3 of fill. Three units (N109 E103, N110 E102, and N111 E101) were dug near the cutbank so the stratigraphy could be correlated with the cutbank profile. The second of these is the deepest and has the most complete stratigraphic section, and is the primary data column for sampling such things as sediments, diatoms, pollen, and so forth. Three more (N112 E99, N113 E98, and N112 E97) were dug near the hearth. A seventh unit (N109 E96, Fig. 3.7) was dug near the base of the bluff so that variability in the deposits away from the longitudinal axis of the creek could be observed. In order to lay out this unit, a large area of fill (mostly slump deposits and stratum 3) was shoveled out and discarded without screening, down to a floor resting at about 93.04-93.15 m (Figs. 3.1, 3.8). Although not by design, the coordinate easting for the southwest corner of each unit is unique, so that if necessary, the individual units can be designated by easting as follows: E96, Unit 2, E97, E98, E99, E101, E102, and E103.

Excavation methods

Before excavation began, both the toe (talus) slope and the bench surface were littered with firecracked rock, chipping debris, mussel shells, and snail shells, most of which derived from the Archaic and Late Prehistoric occupations near the top of the bluff. Much of this was raked away at the outset, but before excavation began in each square, loose sand and intrusive cultural debris were carefully troweled and brushed away until the hard, cemented bench surface was fully exposed. Transit readings on the initial sloping surface were recorded in each corner, and additional elevations were recorded on sketch maps of units crossed by small gullies.

Excavations were done in 5 cm arbitrary levels, since stratigraphic boundaries were too diffuse to recognize while digging. The initial level in a unit was generally wedge-shaped in section as a result of the northeastward slope of the bench surface. The depth of the first level was usually adjusted so that the level floor extended completely across the unit. In the most extreme case, the first level was 39 cm thick in one corner. In two units, the second level was 10 cm thick. Table 3.1 shows all levels and their estimated volumes. One unit (N113 E98) was dug hurriedly on April 16-17, 1980, just before the rising reservoir covered the bench. The purpose of the unit was to search for additional ^{14}C samples associated with the mussel shell-bearing surface at the base of stratum 2A, and because of time limits, abbreviated excavation techniques were used: 10 cm levels were dug until the surface was approached at 92.20 m, then the last 10 cm were removed as two 5 cm levels (Table 3.1).

Table 3.1. Excavation Levels and Level Volumes.

N109 E103	**Volume (m^3)**	**N110 E102**	**Volume (m^3)**	**N111 E101**	**Volume (m^3)**
93.14-92.90	0.1225	93.08-92.90	0.0475	92.89-92.80	0.0100
92.90-92.85	0.0500	92.90-92.80	0.1000	92.80-92.70	0.1000
92.85-92.80	0.0500	92.80-92.75	0.0500	92.70-92.65	0.0500
92.80-92.75	0.0500	92.75-92.70	0.0500	92.65-92.60	0.0500
92.75-92.70	0.0500	92.70-92.65	0.0500	92.60-92.55	0.0500
92.70-92.65	0.0500	92.65-92.60	0.0500	92.55-92.50	0.0500
92.65-92.60	0.0500	92.60-92.55	0.0500	92.50-92.45	0.0500
92.60-92.55	0.0500	92.55-92.50	0.0500	92.45-92.40	0.0500
92.55-92.50	0.0500	92.50-92.45	0.0500	92.40-92.35	0.0500
92.50-92.45	0.0500	92.45-92.40	0.0500	92.35-92.30	0.0500
92.45-92.40	0.0500	92.40-92.35	0.0500	92.30-92.25	0.0500
92.40-92.35	0.0500	92.35-92.30	0.0500	92.25-92.20	0.0500
92.35-92.30	0.0500	92.30-92.25	0.0500	92.20-92.15	0.0500
92.30-92.25	0.0500	92.25-92.20	0.0500	92.15-92.10	0.0500
92.25-92.20	0.0500	92.20-92.15	0.0500	92.10-92.05	0.0500
92.20-92.15	0.0500	92.15-92.10	0.0500	92.05-92.00	0.0500
92.15-92.10	0.0500	92.10-92.05	0.0500	92.00-91.95	0.0500
92.10-92.05	0.0500	92.05-92.00	0.0500	91.95-91.90	0.0500
92.05-92.00	0.0500	92.00-91.95	0.0500		
92.00-91.95	0.0500	91.95-91.90	0.0500		
91.95-91.90	0.0500	91.90-91.85	0.0500		
		91.85-91.80	0.0500		
		91.80-91.75	0.0500		
		91.75-91.70	0.0500		
		91.70-91.65	0.0500		
		91.65-91.60	0.0500		
		91.60-91.55	0.0500		
TOTALS (m^3)	**1.1225**		**1.3975**		**0.91**

(continued on following page)

(Table 3.1, continued from previous page)

N112 E99	Volume (m^3)	N113 E98	Volume (m^3)	N112 E97	Volume (m^3)
92.89-92.60	0.1033	92.72-92.50	0.0897	93.14-92.75	0.2971
92.60-92.55	0.0500	92.50-92.40	0.1000	92.75-92.70	0.0500
92.55-92.50	0.0500	92.40-92.30	0.1000	92.70-92.65	0.0500
92.50-92.45	0.0500	92.30-92.20	0.1000	92.65-92.60	0.0500
92.45-92.40	0.0500	92.20-92.15	0.0500	92.60-92.55	0.0500
92.40-92.35	0.0500	92.15-92.10	0.0500	92.55-92.50	0.0500
92.35-92.30	0.0500			92.50-92.45	0.0500
92.30-92.25	0.0500			92.45-92.40	0.0500
92.25-92.20	0.0500			92.40-92.35	0.0500
92.20-92.15	0.0500			92.35-92.30	0.0500
92.15-92.10	0.0500			92.30-92.25	0.0500
92.10-92.05	0.0500			92.25-92.20	0.0500
92.05-92.00	0.0500			92.20-92.15	0.0500
92.00-91.95	0.0500				
91.95-91.90	0.0500				
TOTALS (m^3)	**0.8033**		**0.4897**		**0.8971**

N109 E96	Volume (m^3)	Unit 2	Volume (m^3)
93.08-93.00	0.0475	92.68-92.38	0.095
93.00-92.95	0.0500		
92.95-92.90	0.0500		
92.90-92.85	0.0500		
92.85-92.80	0.0500		
92.80-92.75	0.0500		
92.75-92.70	0.0500		
92.70-92.65	0.0500		
92.65-92.60	0.0500		
92.60-92.55	0.0500		
92.55-92.50	0.0500		
92.50-92.45	0.0500		
92.45-92.40	0.0500		
92.40-92.35	0.0500		
92.35-92.30	0.0500		
92.30-92.25	0.0500		
92.25-92.20	0.0500		
92.20-92.15	0.0500		
92.15-92.10	0.0500		
92.10-92.05	0.0500		
92.05-92.00	0.0500		
TOTALS (m^3)	**1.0475**		**0.095**
GRAND TOTAL	**6.7626 m^3**		

A transit was used for elevation control — that is, for checking level floors, measuring the elevation of objects found in situ, and setting pins in walls for profile stringlines. An effort was made to locate and record as much cultural debris as possible in place. Objects such as chert flakes, small bits of charcoal, mussel shells, bones, and possible manuports (pebbles that appeared too large to have been water-deposited) were drawn on a level plan and given individual item numbers where necessary, and an elevation was recorded for the surface on which the object was resting. Fill was dry screened through 1/4" mesh hardware cloth. Anything retained on the screen was saved, including artifacts, baked clay fragments, bone fragments, snails, hackberry seeds, charcoal, fossil wood, chert pebbles, rhizoconcretions, irregular calcareous aggregates, ferromanganese concretions, and Goliad sandstone clasts. All of this material was later sorted and weighed or counted. Unit N113 E98 represents an exception to this procedure; snails, concretions, fossil wood, and clastic material were not collected from the screen in this one unit (a small collection of snails was picked in the lab from a bone deposit matrix sample). Excavation was done with shovels, except when special care in exposing a feature or an artifact, or cleaning a profile wall or floor was necessary.

Preventing contamination

Contamination (objects introduced by accident into an unrelated context) is not ordinarily a major concern in most archeological excavations, but in the bench deposits, cultural debris was so sparse that almost any degree of contamination was regarded as unacceptable. Some special measures were taken to prevent contamination. Slump deposits were carefully removed from the bench before excavation. Smoking was banned, to prevent contamination of radiocarbon samples. One recurrent problem was

that the area reserved for screening was muddy with discarded slump debris, and quite a few small flakes from the blufftop deposits were present. To prevent these being tracked into active units, burlap bag "doormats" were provided for each unit, and excavators were asked to wipe their feet before entering the unit. Wet screening was not done during the bench excavations, so there was no possibility of bedload material being introduced from a pump intake (as in the blufftop excavations the previous summer).

Matrix ("constant volume") samples

During the excavation of each level, a block of fill approximately 25 cm square was left standing in the southwest corner to be collected as a general-purpose matrix sample. These generally amounted to about two or three liters in volume, averaging about 2.5-3.0 kg in weight when dried. Matrix samples spanned the entire thickness of levels greater than 5 cm, with the width of the column reduced accordingly so as to keep the volume roughly constant. Samples were collected in double paper bags, which allowed the sediment to dry without the addition of any fungicides.

In retrospect, a better plan might have been to collect the matrix as a column sample from the profile of the completed pit. That method allows for subdivision of samples into smaller units, makes it possible to avoid crosscutting stratum boundaries, and eliminates the possibility of forgetting to collect a sample. On the other hand, large column samples like these are difficult to extract from dry pit walls.

In the laboratory, matrix samples from two units (N109 E96 and N110 E102) were subsampled for grain-size analysis and then the remainder of the sample was washed through graduated geologic sieves to extract snails (details of the procedure can

be found in the chapter on snails). Four matrix samples supplied sediment for radiocarbon assay of sediment organics. Un-oriented peds or sediment aggregates were extracted from matrix sample bags (N111 E101) for micromorphological studies, since no oriented samples were collected in the field.

Pollen/phytolith samples

Small sediment samples that could be used either for pollen or phytolith analysis were collected from the top of each matrix block before it was bagged. No phytolith analysis has been done, but one column of pollen samples (all from N110 E102, except for one sample from N109 E103) was analyzed by Richard Holloway, with the excess sample portions returned for curation.

Although these samples were intended as general-purpose pollen or phytolith samples, some of them were later subsampled for diatom analysis, magnetic susceptibility, and soil lipid analysis as well.

The collection protocol for these "phytopol" samples was as follows:

1) Approximately a centimeter of fill was troweled off the surface of the matrix block to expose a fresh surface;

2) The trowel to be used for collection was washed in distilled water;

3) The sample was collected from a thin layer, ideally no more than a centimeter thick, and placed in a plastic bag which was immediately sealed;

4) Samples were not treated with phenol or other fungicides. Instead, the tail of the plastic bag was loosely wrapped around the sample, which was secured and placed in a labeled paper bag. This kind of closure was intended to allow enough ventilation for moisture to escape very slowly, yet prevent contamination by airborne pollen.

These "phytopol" samples are therefore derived from the upper 2 cm (or less) of a 5 cm level, and most of the remainder of the matrix sample is generally derived from the lower 3 cm. Figure 3.4 is a schematic drawing showing the relative vertical position of the different kinds of samples. In the case of 10 cm levels, one sample was collected from the top of the level and another from the midpoint (except in N113 E98, where only the top sample was collected). These supplementary samples are as follows:

N110 E102 92.90-92.80 (upper at about 92.89, lower at about 92.85)
N111 E101 92.80-92.70 (upper at about 92.79, lower at about 92.75)
N112 E97 93.14-92.75 (about 92.80)

In all but one case, samples were not collected from the initial level in a unit, since only a centimeter of fill would insulate these from the eroded surface. In addition to these standard samples, a few special samples were collected in the field and lab, including two from a probable root mold in N110 E102, one from the fill of Feature 6, another from sediment under the associated core, and several samples collected in the lab from artifacts or other objects. There is also a column of 11 small sediment samples that Joan DeCosta and I collected from the exposed wall of the main blufftop excavation block (at N97 E96) in April, 1981; some of these have been subsampled for diatom analysis. These, plus similar samples collected by David Brown during his excavations,

furnish samples of the upper sediments for comparison with their counterparts from the bench.

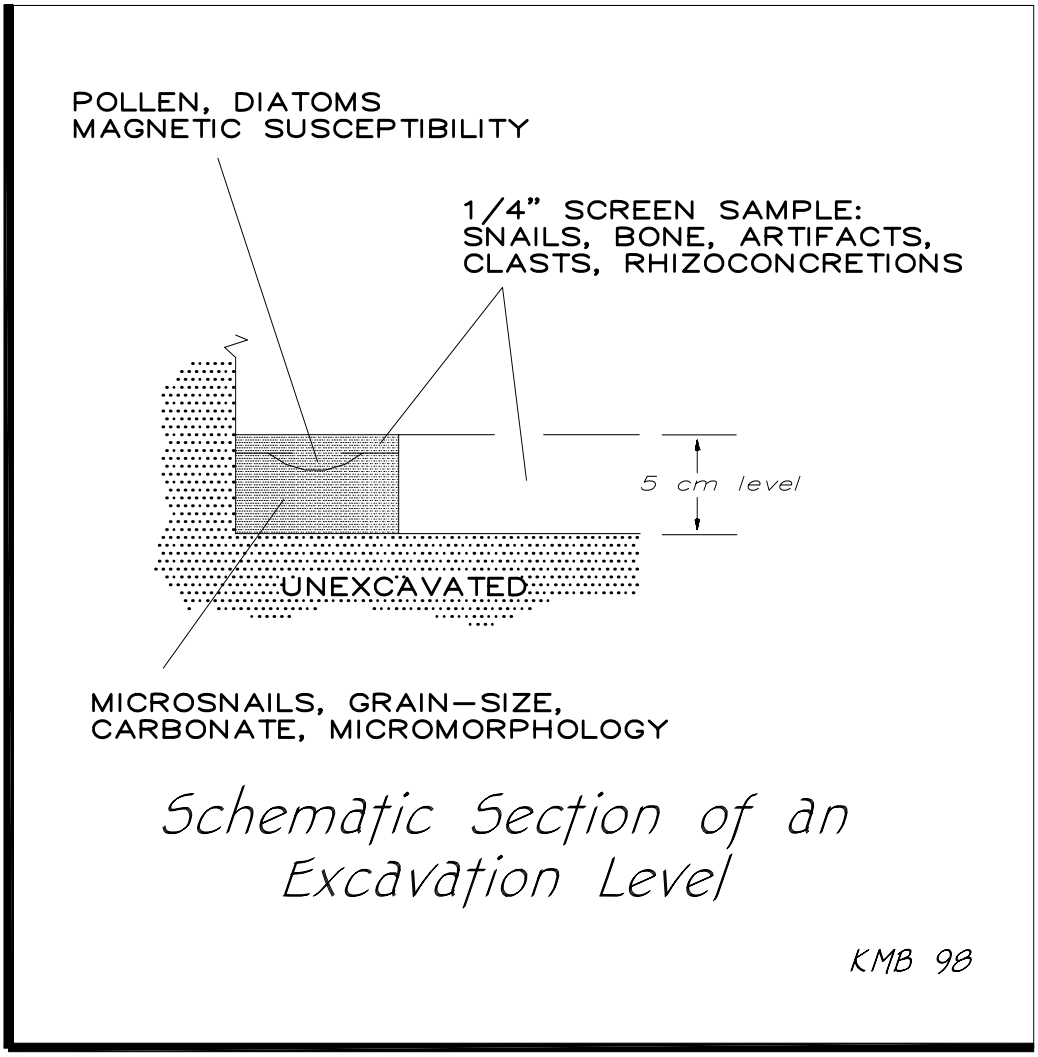


Figure 3.4. Schematic View of an Excavation Level. This is a diagrammatic section through the south end of a typical 5 cm excavation level, to show the spatial relationships of the different kinds of subsamples.

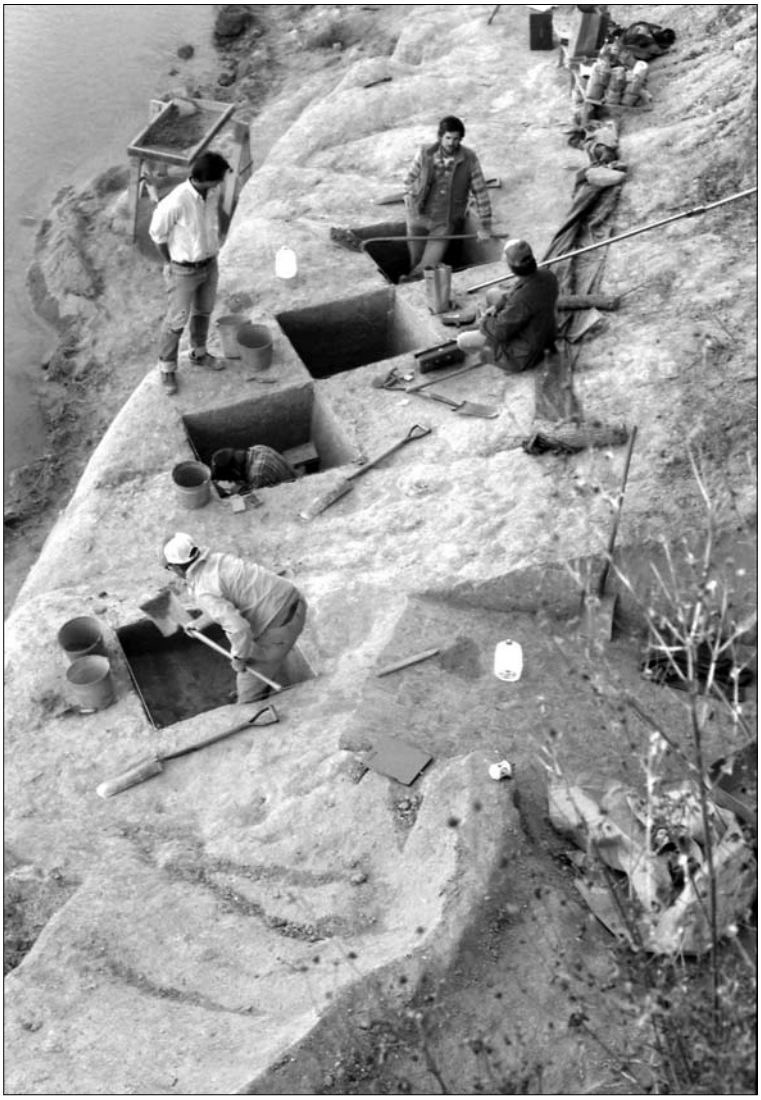


Figure 3.5. Excavations in Progress, Looking Southeast. View downward from blufftop, December 20, 1979. Excavation of unit N112 E97 is underway in foreground. Corner of Unit 2 is barely visible to the left; N113 E98 has not yet been opened. Floor of cut to right rests a few centimeters above the base of stratum 3.

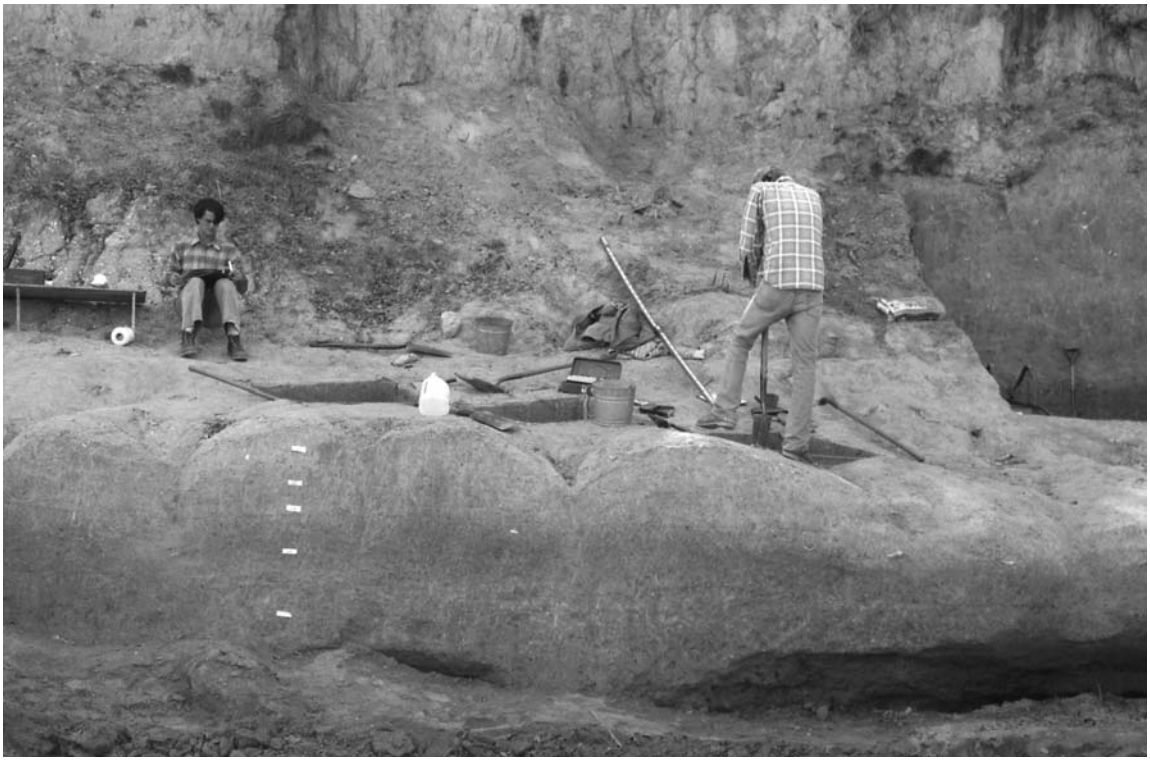


Figure 3.6. Excavations in Progress, Looking Southwest. View from midchannel of excavations in three easternmost units, December 4, 1979. Tags in foreground mark (top to bottom) strata 2D, 2C, 2B, 2A, and 1. Will Goetzmann (left) sits at base of toe slope.

Figure 3.7. Excavation of Unit N109 E96 into Artificial Cut. Looking south-southeast at Will Goetzmann working in N109 E96, December 21, 1979. Note bags of screened fill to right. Dark zone rising to about 50 cm above floor of artificial cut is stratum 3. Rock cluster is out of view behind equipment in corner.

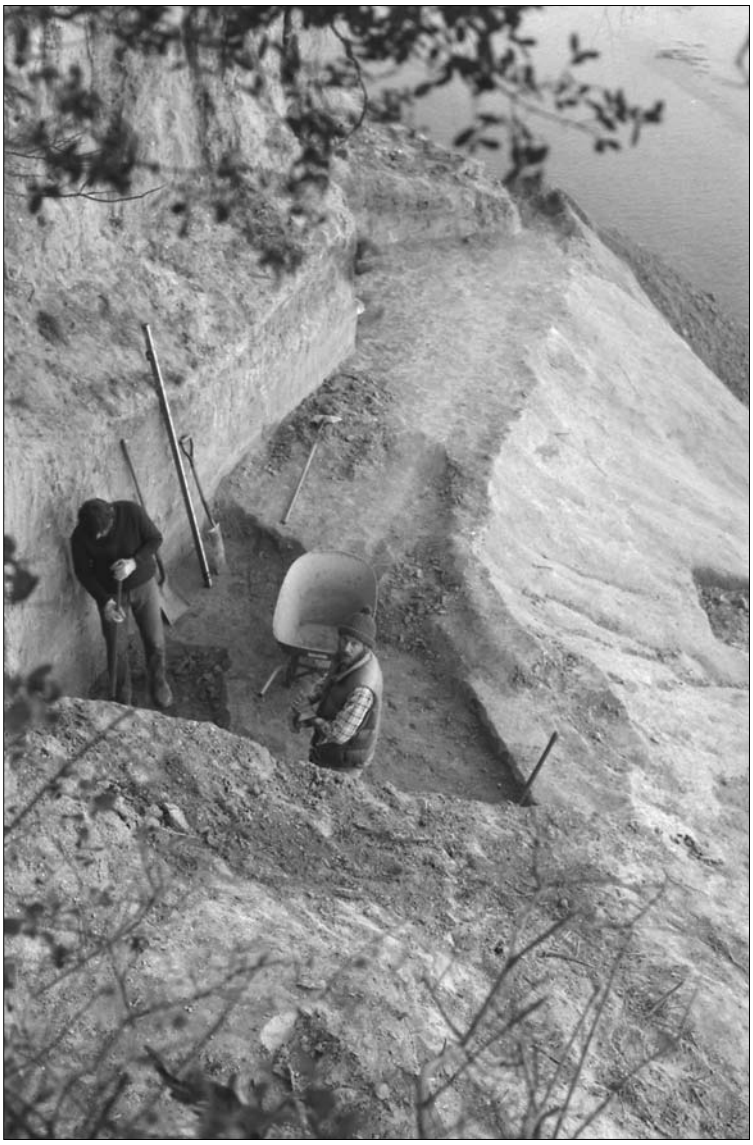


Figure 3.8. Removal of Stratum 3 Fill to Create an Artificial Floor. Looking northwest from blufftop at clearing of overburden. backfilled Unit 2 lies at right edge of frame. Photo November 29, 1979.

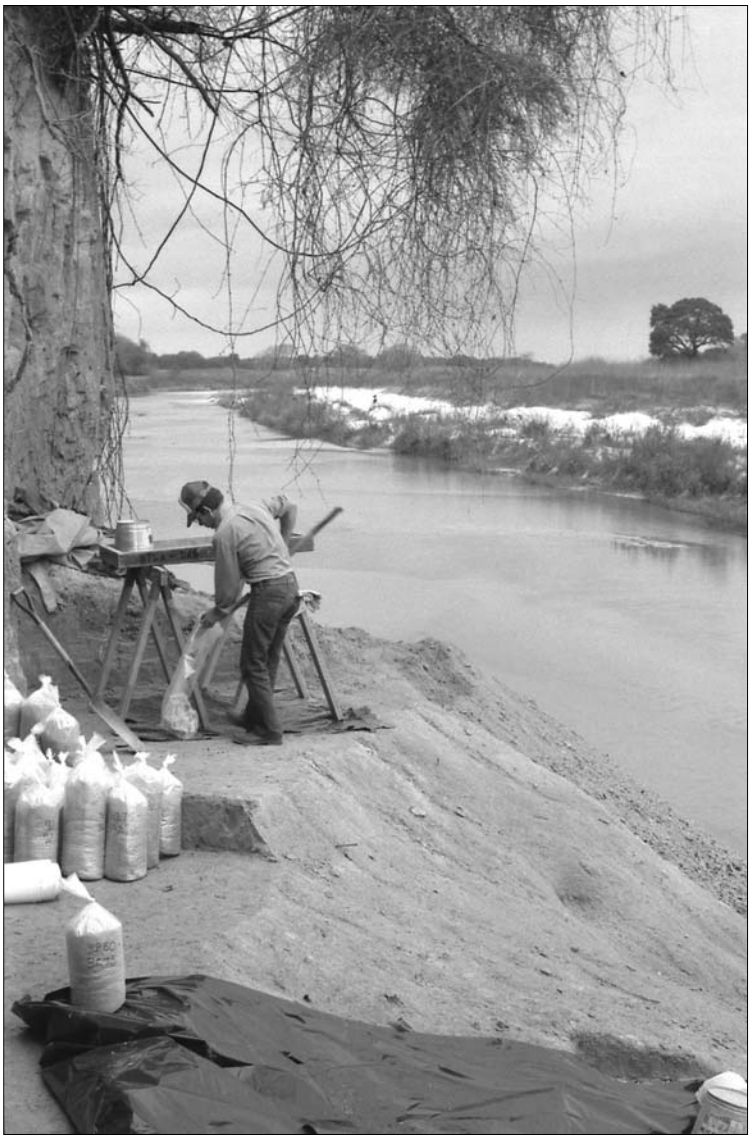


Figure 3.9. Collecting Screened Matrix. Looking upstream (northwest) at Bill Birmingham collecting N109 E96 matrix from plastic tarp under 1/4 inch screen. Birmingham is standing on stratum 3 sediments (large nail driven horizontally into sloping face in foreground marks basal contact), in the general area where a mud dauber nest was unearthed. Secondary datum is located behind and to left of screen. Photo December 21, 1979.

Bulk sediment sampling from N109 E96

In the unit closest to the bluff (N109 E96), the matrix and "phytopol" samples were collected as described, then all of the remaining fill passing through the 1/4" screen was collected on a tarp underneath, saved by level in large plastic bags (Fig. 3.9), and hauled to the Vertebrate Paleontology Laboratory in Austin, where it was washed through fine mesh window screen to recover small vertebrate and invertebrate remains. Approximately a cubic meter of fill was treated this way. Although little bone was recovered from this particular unit, the sample of snails from the site was greatly expanded, and a reliable estimate of the amount of "ambient" or "background" subfossil bone in the sediments was obtained.

Unit 2 fill

As explained by David Brown (1983:17), part of the fill removed from Unit 2 (from the eroded bench surface down to the level of the Feature 5 fired surface) was wet screened through nested 1/4" and 1/8" mesh hardware cloth. The unscreened part of the fill was replaced in the unit as backfill at the end of the June, 1979 project. No lithic cultural debris was found anywhere in the unit. The screened residue was bagged, and in September, 1982, about three-fourths of this residue was again wet-screened, this time through nested #12 and #35 geologic sieves. Examination of this residue suggested that some contamination by snail and mussel shell fragments from the upper deposits had occurred during the original wet-screening process. Very little bone was seen (laboratory notes, September 10, 1982). Residue was rebagged in 1993 and remains in curation, but has played no part in the analysis of the site.

It is very critical to note that none of the charcoal submitted for radiocarbon assay, and none of the microfauna in lot B-149 (46 fragments representing at least 29 elements) came from wet-screening. Instead, all charcoal and all bone were collected by hand-picking.

The reason this distinction is crucial is that contamination can occur during wet-screening, either when foreign material is introduced through the pump intake, or when screens are not thoroughly cleaned between lots of material. None of the material analyzed for the present project was recovered by wet-screening.

Block removal of Feature 5

On April 18, 1980, I cut a four-sided trench around Feature 5, leaving an isolated block of matrix about 21 cm on a side in the center for removal to the archeology laboratory (Fig. 3.10). This block contains the core of the fired area, although some of the periphery has evidently been lost. A small sample of the fired surface was removed in the UTSA-CAR lab for lipid analysis. The surface and all sides of the block have also been inspected closely in hopes of finding additional charcoal that could be used for AMS dating; none has been found. The block remains available for further studies, although the surface has been considerably altered by repeated troweling and by sampling for various studies.

Field observations and their recording

The primary record of the bench excavations was the daily journal, which has detailed information on particular units and levels when something noteworthy was found. A log of levels excavated was maintained, but no level forms were filled out.

Figure 3.10. Feature 5 Isolated for Removal. Looking north at north wall of unit N113 E98 in foreground. Beyond is Feature 5 completely isolated for removal as a matrix block. Unit 2 lies to the left. Photo taken April 18, 1980; rapidly rising waters of Coleto Creek Reservoir can be seen in upper right corner.

Instead, I recorded information on the sediments by photographing and drawing profiles of all four walls of every excavation unit (except N113 E98, where only the west and north walls were profiled), by drawing floor plans when horizontal variability was apparent, and by later analyzing sediment samples for grain size and carbonate content.

Inclusions and features, whether cultural or noncultural, were drawn on level floor plans by crew members, and elevations were recorded with transit shots. Special features (root mold, ravine outwash, pits) were described in the daily journal; no feature forms were used. The feature numbers assigned (5 through 7) are a continuation of numbers assigned in the main block excavations by David Brown. A radiocarbon sample log and color and black-and-white photo logs were maintained. Film roll numbers (B/W rolls 5-12, color transparency rolls 5-9) assigned are a continuation of numbers assigned in the main block excavations by David Brown. Large format cameras were not available, so photography was exclusively 35 mm. Kodak Plus-X film was mostly used for black-and-white, Kodachrome transparency film (plus one roll of Kodacolor color negative film) for color photography. One roll of black-and-white infrared film was taken of the unit N109 E96 profiles, but since I did not have an infrared filter, the results were the same as conventional black-and-white film.

Associated geologic samples

A few geologic samples from the site environs were collected. Two samples of bedload material collected underwater from the creek bed have already been described in Chapter 1. Some samples of Goliad sandstone from a knickpoint in the ravine southwest of the bench area (Figs. 1.30, 1.32) were collected. Two narrow profiles on the Lissie terrace cutbank were cleaned (locations 1 and 2 in Fig. 1.30), and some small sediment samples were collected. Two samples from Lissie section 1 were analyzed for diatoms, to check for possible reworking of Lissie-age diatoms into the bench sediments (discounted by the analysis). There are also samples of pedogenic(?) carbonate obtained from backhoe trenches 2 and 3 in Area B during the Flume #3 project.

Lighting conditions and their effect

Nearly all the fieldwork was done under wintertime lighting conditions. Winter skylight is weak, diffuse (multidirectional), and deficient in the red or warm end of the visible spectrum. This not only made photography difficult (an electronic flash was unavailable), it also made viewing the profiles more difficult in some respects. In wintertime the bench was never in direct sunlight except just after sunrise, when the edge along the cutbank was lit for a brief time. Even at noon the excavations lay in complete shadow. Lighting was always best for the south or west wall, depending on time of day, and stratum descriptions for excavation profiles are based mainly on those two walls. Minor stratigraphic units defined from the south or west wall were frequently difficult and sometimes impossible to trace around all four walls, which accounts for some of the minor discontinuities in the profiles.

Diffuse winter skylight, despite lack of color saturation, tends to accentuate color differences at the expense of textural differences. Nevertheless, sediment analysis shows that the strata defined in the field have textural validity, and it is quite possible that in strong, direct summer light the subtle bench strata would have been nearly invisible. The severest lighting problems occurred in N109 E96, set well back in a notch cut into the toe slope. Here the stratigraphy was nearly impossible to define with confidence, but this may also have been partly due to addition of colluvial sediments from the valley wall in this area.

OVERVIEW: KINDS OF DATA RECOVERED

In addition to the small number of cultural features and stone artifacts that were discovered in the bench deposits, an interesting array of data on past habitats and

environments was found in the bench deposits. The different kinds of proxy paleoenvironmental data are reviewed in their respective chapters and appendices, but a brief overview of the classes of data and their provenience units is given here.

Grain-size and carbonate content samples

A composite column consisting of three samples from N109 E103 plus 25 from N110 E102, as well as one sample from the cutbank (stratum 2E), two from N109 E96, and three from Lissie terrace sections 1 and 2. These have pipette analysis of fines, and estimation of carbonate content (by weight loss after acid digestion). An unsuccessful attempt was also made to measure organic content by the loss-on-ignition method. Samples from the excavation units were extracted from general-purpose matrix sample bags. There are also some sieved samples from the upper deposits, for which fines were not analyzed.

Clasts

1/4" screen sample: chert pebbles, Goliad sandstone nodules, and carbonate nodules (either pedogenic or clastic in origin) saved from all units.

Rhizoconcretions, ferromanganese concretions

1/4" screen sample: large samples from all units.

Micromorphology samples

Seven un-oriented aggregates from N111 E101, extracted from matrix samples.

Magnetic susceptibility samples

Five columns of samples (N109 E103, N110 E102, N111 E101, N112 E99, and N109 E96) extracted from "phytopol" samples, plus some samples from the cutbank, Feature 6, for a total of 117 samples from the bench deposits; 10 more samples come from the upper deposits at N97 E96. Altogether, 127 samples were analyzed.

Sediment lipid samples

Three small samples were analyzed, one from the hearth surface (Feature 5) and two background samples from as nearly the same elevation as possible: N112 E99 (92.40-92.35) and N113 E98 (92.40-92.30). Both plant and animal lipids were identified.

Sediment samples assayed for radiocarbon and carbon isotopes

Four sediment samples, all from N111 E101, were submitted for radiocarbon assay of the humin fraction. These subsamples (ranging in dry weight from 1.02 to 2.0 kg) were extracted from the general-purpose matrix samples, and $\delta^{13}C$ values were determined for all of them. These, plus samples of wood charcoal submitted for assay are described in the chapter on radiocarbon dating.

Animal bone

Almost all of the bone found in the bench deposits is from microvertebrates. Relatively little came from screening; instead, most microfauna were found concentrated around Feature 5, and were collected by hand-picking in the field or by scooping up small quantities of loose dirt and bone during excavation. Some items were found and drawn in place. Two of the largest, a raccoon humerus and a turtle plastron, both with cutmarks,

were found in the cutbank (provenience is shown in Fig. 3.1). Bone is very well preserved, and the fauna is taxonomically diverse and informative.

1/4" screen sample: a small quantity of microvertebrate bones from various units.

bulk fill from N109 E96: a small quantity of microvertebrate bones.

hearth deposit from Unit 2 and N113 E98: a large quantity of microvertebrate bones recovered by picking fragments from the excavation floor and by sieving small quantities of loose sediment through a fine mesh sieve.

Snails

Snails are fairly well preserved. There is mechanical breakage of some taxa, but little evidence of chemical dissolution. The snail fauna is abundant, diverse, and possibly the most informative proxy environmental indicator.

1/4" screen sample: a moderately sample of large-bodied taxa, recovered from all units.

bulk fill from N109 E96: a very large sample of small (microsnail) to large-bodied taxa.

snail columns: two columns of sediment samples from N109 E103 (21 samples, total dry sediment weight 69.42 kg) and N110 E102 (26 samples, total dry sediment weight 68.70 kg), processed through geologic sieves to extract microsnails.

Freshwater mussels or sphaeriid clams

Only about 44 specimens were recovered. The freshwater mussels are powdery, poorly preserved, and for the most part were found *in situ* but were difficult to recover intact.

They are believed to have been brought to the site by human occupants, but are quite informative about water depth and runoff conditions.

Pollen

Pollen column: analysis of a composite column consisting of one sample from N109 E103 and 24 samples from N110 E102, from the "phytopol" samples described earlier. Pollen is badly degraded and so few grains remain that none of the samples are statistically usable. The pollen tells little about environmental conditions.

Diatoms

Diatom column: similar to the grain-size samples, a composite column consisting of three samples from N109 E103 and 27 from N110 E102, but extracted from the "phytopol" samples; plus two samples from the upper deposits, two from Lissie terrace section 1, and one sample from the cutbank (stratum 2E).

Plant macrofossils: charcoal, seeds, resin or amber

Except for rhizonconcretions (listed separately above), plant macrofossils are few in number and are not very environmentally informative. About 28 charcoal samples were logged, although microscopic examination of some of these showed some were actually small, black, ferromanganese aggregates. Samples submitted for radiocarbon assay are described in more detail in the chapter on radiocarbon dating. Nine samples of wood charcoal were submitted for wood species identification, of which four were large enough for identification to the generic level (all four were later submitted for radiocarbon assay). A single small fragment of a possible charred but unidentified monocotyledon was recovered from N113 E98. A small fragment of unidentified tree resin, sap, or amber was recovered from screened bulk matrix in N109 E96. About nine calcareous hackberry seed

tests were recovered, some of them having a charred appearance. Many of these were discovered fortuitously in the laboratory, among samples of snail shell or other material recovered from the 1/4" screen.

CULTURAL EVIDENCE FROM THE BENCH DEPOSITS

Analysis of the cultural evidence recovered from the bench deposits is beyond the scope of the present work. However, a summary statement about the findings may be in order here. By the late Holocene, Berger Bluff had clearly become a major base camp with an extensive midden of shell, bone, and lithic debris capping the bluff (D. Brown 1983). The situation some 8,000-10,000 years earlier, however, was different. Human occupation at that time appears to have been transitory, of very limited duration, and with little impact on the site. The earliest use of the site is believed to have been as a foraging station rather than as a residential site, so it is not surprising that the most important and informative cultural evidence from the bench consists of animal bone and freshwater mussels, rather than tools and manufacturing debris.

Lithic reduction (including biface thinning or resharpening) clearly was done at the site at this early period, for there are cores (including a small single-facet polyhedral core), a possible core-trimming flake, and at least one textbook example of a lipped soft-hammer biface thinning flake (Fig. 3.11, middle row). An *in situ* scatter of flakes from a single chert cobble reduction episode was also excavated near the top of unit N109 E103, and a small biface preform reject was discovered during trenching for removal of Feature 5 (Fig. 3.11, top row). There are no finished tools, however, except possibly for a bifacially flaked chopper (Fig. 3.11, top row). Tool manufacture or refurbishing was clearly a rather minor activity at the site, or at least the part that remained for us to

investigate, and although the bench deposits are clearly Paleoindian in age, none of the lithic debris bears any hallmarks of other known Paleoindian lithic traditions. Instead, all of the lithic debris is indistinguishable from generalized Archaic or Late Prehistoric debris in south Texas.

Evidence of fire, in the form of small fired clay nodules, heat-altered chert (potlids, heat-discolored or fire-crazed fragments), and calcined and heat-discolored snail or mussel shell is fairly common, although not much charcoal remained in the sediments.

Three cultural features were formally investigated during the two 1979 excavation projects. Feature 5, located in Unit 2 (lower stratum 2B; stratigraphy will be described in the chapter on sedimentology), is a small unprepared hearth (a well-baked but otherwise unmodified sediment surface) with an associated deposit of microvertebrate remains (extending into unit N113 E98) that is interpreted as a human latrine deposit (K. Brown 1996). Feature 6 is a small pit that lay at the grid point between two units (N110 E102 and N111 E101, basal stratum 2A). The fill contained nothing except some baked clay nodules and iron-stained snail shell, but a small chert core (Fig. 3.11, top row) lay next to the pit. Feature 7 is another similar pit located in N109 E96 (stratum 2C?). The fill contained snail shell, small sandstone and carbonate nodules, fossilized wood, small bits of wood charcoal, and bone fragments of eastern mole, (probable) kangaroo rat, unidentified mouse-sized mammal, and unidentified turtle and frog.

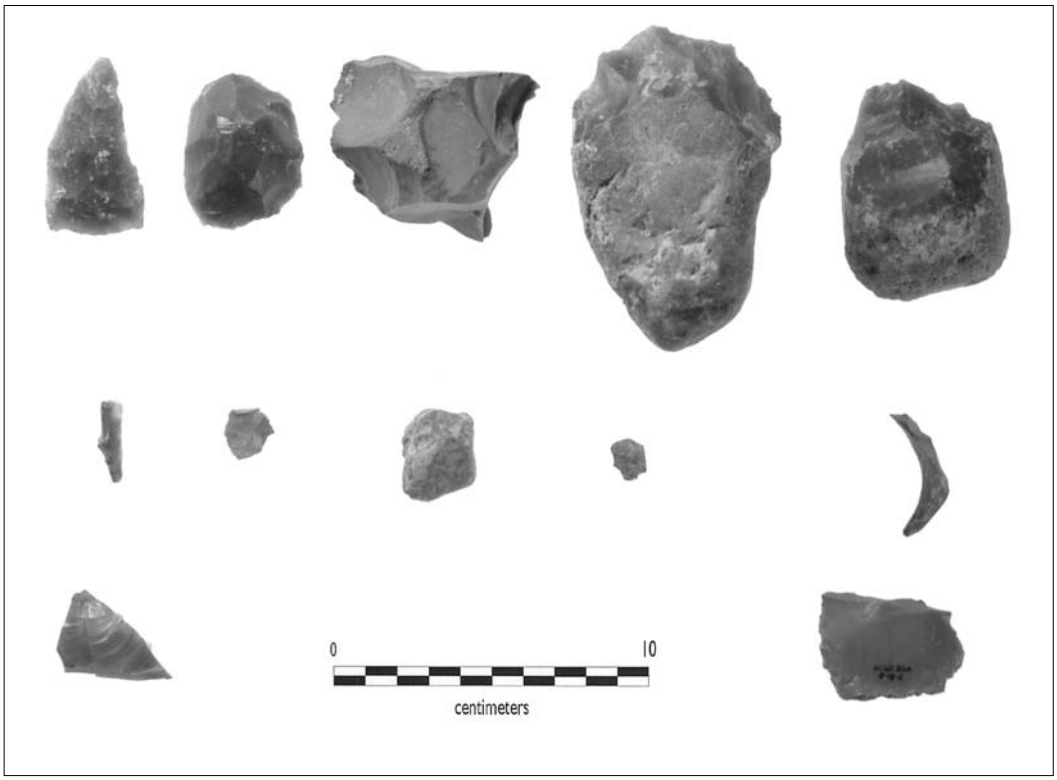


Figure 3.11. Cultural Debris from the Bench Deposits. Examples of stone tools, chipping debris and fired clay found during excavation; selection is biased toward larger items. Top row (left to right): chert biface preform reject, found while trenching Feature 5 (lot B-151, N114.25 E98.49, 92.184 m); small polyhedral single-facet chert core (platform side down) found next to Feature 6 (lot B-87-1, N111 E101, 91.97 m); chert cobble core dislodged from cutbank (lot B-152, stratum 2C?); chert cobble chopper found near Feature 7, but below detection level (lot B-141-1, N109 E96, 92.25 m); large chert core-trimming flake from cutbank, stratum 2A (lot B-153, 16.38 m profile mark, elevation approximately 92.29 m). Middle row (left to right): burin spall-like collapsed chert biface edge fragment (lot B-130, N109 E96, 92.75-92.70 m); lipped biface thinning flake with post-removal heat crazing and potlidding (lot B-34, N110 E102, 92.90-92.80 m); unmodified chert pebble (manuport, lot B-3, N109 E103, 92.90-92.85 m); fired clay nodule (lot B-114, N112 E97, 92.70-92.65 m); chert thermal spall (lot B-144, N109 E96, 92.20-92.15). Bottom row (left to right): chert bipolar core remnant (lot B-41-1, N110.62 E102.01, 92.51 m); chert primary flake (lot B-15-2, N109.31 E103.94, 92.53 m).

Two other features are known but were not studied. One is a possible hearth (in stratum 2D) encountered while clearing stratum 3 overburden (Figs. 3.1, 3.2, 3.7), consisting of a cluster of sandstone nodules without any visible charcoal. The feature was not documented nor was a feature number assigned. The other feature is a definite hearth that was noted by Bill Birmingham during a visit to the site in the mid-1960s. It consisted of a ring of sandstone nodules with an orange fired interior, probably located somewhere in the vicinity of the three easternmost excavation units, or perhaps slightly to the south, but at a slightly higher level that has since been removed by deflation of the bench surface (Bill Birmingham, personal communication, 1983 and 1998). Since it appears that the resistant bench surface has been lowered very little by erosion since its exposure, this feature must have lain just above the level from which the 1979 excavations began, but disappeared sometime during the preceding dozen or so years.

ANALYSIS METHODS: GENERAL PRINCIPLES

As the chapter on depositional history will show, a prominent feature of the bench deposits is the cyclic banding visible in the cutbank. A key problem is to identify the meaning of this cyclicity. Chapter 1 has already addressed the scale and significance of cyclic climatic phenomena. Could these bands represent climatic cycles? One way to test whether banding has a climatic origin is to inventory diatoms or snails and discover whether assemblage composition changes at stratigraphic boundaries.

Some data are essentially qualitative in nature — that is, some things such as mussel shells are informative, but occur in samples too small for quantitative treatment. Other items, such as animal bones, are abundant enough for quantitative study, but are too spatially clustered to illustrate long-term trends in abundance. I use rarefaction

methods to check for sample-size effects, but cannot plot vertical trends in vertebrate assemblage composition within the bench. Other kinds of data, such as magnetic susceptibility, carbonate content, or grain-size statistics, furnish single measures that can be plotted vertically and compared among each other.

Two kinds of environmental proxies (snails and diatoms) are abundant, fairly well distributed throughout the bench, and taxonomically diverse. These are best examined by correspondence analysis, which allows case scores to be plotted vertically, level by level, and compared both with other measures (such as grain-size statistics) and with stratigraphic boundaries as defined in the field profiles.

Details of laboratory and analysis methods will be presented in the various chapters and appendices to follow. Table 3.2 lists some of the analysis software employed in various chapters.

Table 3.2. Analysis Software.

Task	**Program**
curve-fitting	Tablecurve 3.12, Excel
descriptive statistics, metric conversions	Excel, CONVERT.EXE*
insolation calculation	INSOLATN.EXE
peak discharge estimation	PEAKFQ.EXE
rarefaction analysis	RAREFRAC.EXE, Tablecurve 3.12
grain-size statistics	GRAIN.EXE*
sediment carbonate content	CARB.BAS*
correspondence analysis	MVSP Plus 3.1
radiocarbon calibration	CALIB 4.4
age-depth modeling	Lotus 1-2-3, Excel, Tablecurve 3.12

* Programs written by the author expressly for this project.

References for Chapter 3

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1983 *The Berger Bluff Site (41 GD 30A): Excavations in the Upper Deposits, 1979*. Center for Archaeological Research, University of Texas at San Antonio, *Archaeological Survey Report* 115.

Brown, Kenneth M.

1996 Berger Bluff. Entry in *The New Handbook of Texas*, 1:497-498. Austin, Texas State Historical Association.

Chapter 4: The Depositional Record

INTRODUCTION

This chapter will describe the immediate geologic context of the site, describe the complete stratigraphic section (including the upper deposits), examine the diagenetic history of the sediments, and explore some possible reasons for the cyclic banding visible in the cutbank. Some of this has already been touched upon in Chapter 1, and I will refer to some of the illustrations in that chapter. A key question in this chapter will be to determine which elements of depositional patterning might be due to climatic change and which might be due to fluvial behavior that is intrinsic to Coleto Creek itself. Before addressing these questions, though, it may be appropriate to review some of the biological properties of riparian habitats.

THE FLOODPLAIN ENVIRONMENT

Archeologists often dig in open upland settings, where surfaces may be stable and sediments heavily weathered, or where slow degradation or colluviation are common. Bioturbation and soil development are the dominant processes, biotic remains (bone, shell, charcoal) are often poorly preserved, and the archeological record is likely to be compressed and mixed. Floodplain settings are different. One has only to look at the complex, multi-layered profiles of deep alluvial sites like Devil's Mouth (Johnson 1964:Fig. 5), Arenosa Rockshelter (Patton and Dibble 1982:Fig. 5), or Peace Point (Stevenson 1985:Figs. 4, 5) to see that the geoarcheological potential for complexity, preservation (of stratigraphy and biota), and time resolution is likely to be much higher (Collins 1995:374 ff). Floodplain environments are dynamic. The flood zone is a conduit

for sediment, organic matter, plants, animals, and information — in the sense that changes in environmental conditions either upstream or downstream may be communicated along a riparian corridor. An example would be a downstream increase in channel gradient causing an episode of channel incision that gradually works its way headward. Floodplain environments may be spatially complex; much of the spatial structure is determined by energy gradients associated with stream activity. On the broad flat, floodplains of large rivers, minor elevation differences and hydroperiod (duration of flooding) can determine vegetation type (Shankman 1993, Wharton 1980), while channel migration history may determine the age of tree stands (Brown 1997:Fig. 4.5) or the location of successional assemblages (Brown 1997:Fig. 4.7). A classic study by Shelford (1954, especially Fig. 4) illustrates this spatial complexity. Floodplains of small streams like Coleto Creek cannot be expected to resemble the Mississippi bottoms, but may have shown past spatial complexity in their own right.

Floodplains, especially wooded floodplains, have been characterized as having greater *primary productivity* (Brown 1997:104; Sharitz and Mitsch 1993:323, 344) and plant biomass, and greater *biodiversity* (Gregory *et al*. 1991:544) than surrounding uplands. If true, this ought to be of interest to archeologists since productive and diverse habitats ought to be both an attraction to prehistoric human populations and a ready source of identifiable "ecofacts." For example, Hall (1998) has suggested that floodplains in the Gulf coastal plain are exceptionally productive biologically (Hall's examples actually include at least three different trophic levels, however). However, these generalizations deserve scrutiny. Because the Coleto Creek floodplain appears to have been wetter and more heavily wooded in the Pleistocene, I have looked mostly at floodplains in the southeastern US for comparative data. Annual biomass production

varies widely among Southeastern floodplains, from about 681 to 1607 g/m^2/yr in cases examined by Brinson and others (1981:Table 11). Basal area in upland forests is controlled by precipitation, while riparian forests are largely independent of precipitation (Brinson *et al*. 1981:Fig. 8) and may or may not have greater basal area than upland forests.

Comparing floodplain and upland areas on scales of productivity and biodiversity is more difficult than might be imagined, because there are few ecological studies that encompass both areas, and because many studies focus only on trees and shrubs, ignoring herbaceous or grassy vegetation. A recent study by Megonigal and others (1997) compares productivity of transects in Louisiana and South Carolina floodplain forests with various upland forests. Figure 4.0 is adapted from their Figure 3. They found that net primary productivity was lower on "wet" than "intermediate" and "dry" floodplain sites, and that productivity of upland forests was not significantly different from "intermediate" floodplain sites. Another study on the Sangamon River in Illinois (Fig. 4.1, *B*) found that biomass was actually higher in the upland forest zone than on the floodplain (Johnson and Bell 1976). A second study on the Sangamon River found that bird/mammal population density and biomass and bird species diversity were higher on the floodplain than on the adjacent upland (Blem and Blem 1975).

Ideally, to see how floodplains compare with uplands in terms of productivity and biodiversity, we would like to examine some transects that begin at the streambank, move across the floodplain, up the valley wall, and across the uplands to the nearest drainage divide (Fig. 4.1, *A*). Unfortunately, at least in Texas, there seem to be no cases to study. A number of transects of riparian habitats have been done, but they nearly

always stop at the valley edge (Fig. 4.1, *C-H*), presumably either because the study was originally defined as a study of riparian vegetation only, or because farming and ranching has drastically changed the vegetation outside the valley itself. In most cases, vegetation inventories are for trees, shrubs, or vines only. In cases where gallery forests are embedded in a prairie landscape, the species richness of grasses and forbs might actually be far higher on upland prairie, but if the study is confined to woody vegetation, the prairie is not included.

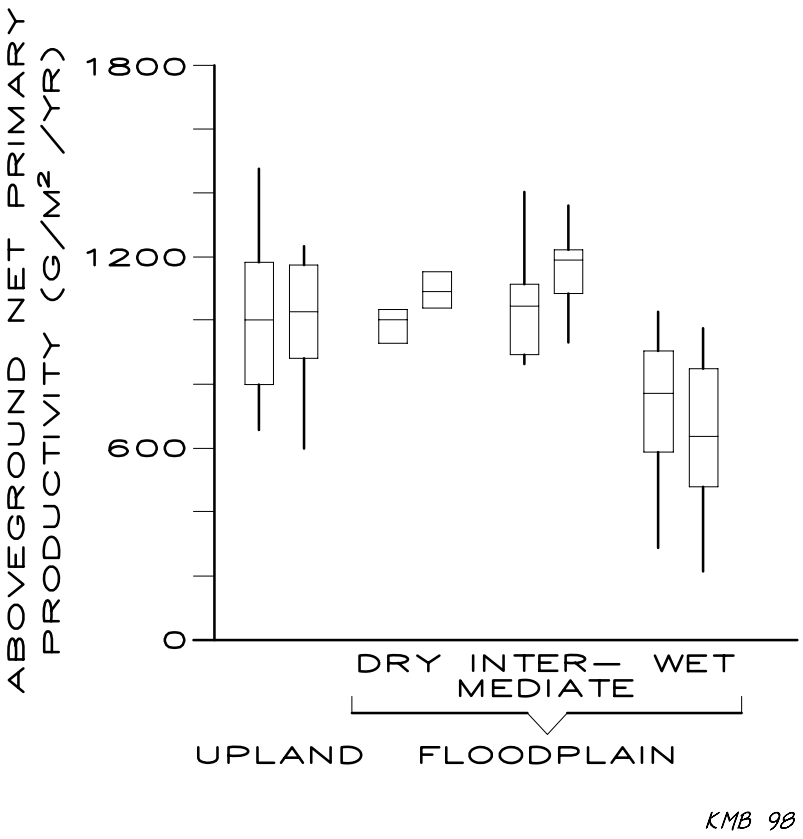
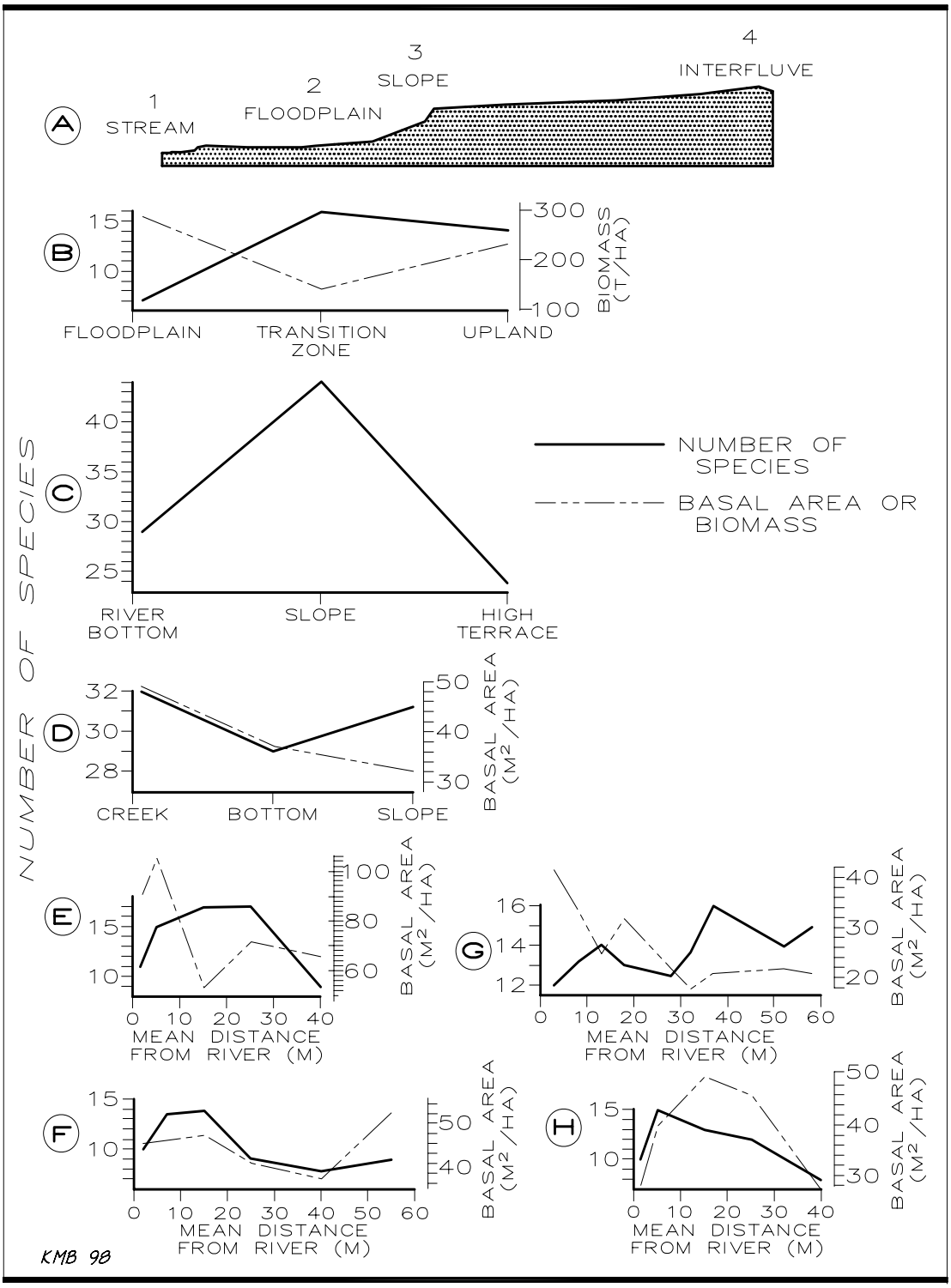


Figure 4.0. Primary Production for Upland and Floodplain Habitats Compared. Box-and-whisker plots of aboveground net primary production ($g/m^2/yr$) for various upland sites in North Carolina and elsewhere (N = 22, 8, respectively) and for floodplain sites in Louisiana and South Carolina (after Megonigal *et a*l. 1997:Fig. 3). Centerline = median, box = 25^{th}-75^{th} percentiles, whiskers = 5^{th}-95^{th} percentiles. These plots show that the upland woodlands are nearly as productive as the "intermediate" floodplain sites.

Figure 4.1 (*following page*). Cross-Valley Traverses of Plant Species Richness and Basal Area. A, an idealized transect that begins at the streambank and extends all the way to a flanking drainage divide; B, Sangamon River, Illinois, trees (Johnson and Bell, 1976); C, Neches River in Hardin, Polk, Tyler, Jasper County; trees, shrubs, vines (Marks and Harcombe 1975); D, Spring Creek, Dallas County; trees, shrubs, vines (Nixon *et a*l. 1991); E, Sabinal River, Bandera County to Uvalde County; trees, shrubs, vines; Wood and Wood (1989:Fig. 2); F, Frio River, Real County to Live Oak County; trees, shrubs, vines; Wood and Wood (1988:Fig. 2);G, San Antonio River, Wilson County; trees, shrubs, vines; Bush and Van Auken (1984:Fig. 2);H, Leona River, Uvalde County to Frio County; trees, shrubs, vines; Wood and Wood (1989:Fig. 2). Dash-dot lines indicate basal area (square meters per hectare) in all cases except panel B, which shows biomass.


A
1
STREAM
2
FLOODPLAIN
3
SLOPE
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INTERFLUVE
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300
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BIOMASS (T/HA)
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TRANSITION ZONE
UPLAND
C
40
35
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25
NUMBER OF SPECIES
NUMBER OF SPECIES
BASAL AREA OR BIOMASS
RIVER BOTTOM
SLOPE
HIGH TERRACE
D
32
30
28
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40
30
BASAL AREA (M²/HA)
CREEK
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MEAN DISTANCE FROM RIVER (M)
KMB 98

Figure 4.1, *C-H*, shows cross-valley transects of species richness and basal area for woodland on various Texas floodplains. Most of these are for woody vegetation only, and except for the Neches River floodplain (*C*), stop at the valley edge. Species richness refers to the number of woody plant taxa counted in a given sample plot along a transect from the stream bank to the upslope end of the transect. These plots show that both the diversity and cross-valley spatial distribution of woody plants vary considerably for different rivers and creeks. Perhaps the only common pattern is the reduction of species richness (and sometimes basal area) immediately along the stream bank. The same pattern can be seen in transects from Oregon and California (Gregory *et al*. 1991:Fig. 7). This is a typically Holocene pattern that occurs because flood stress restricts streambank woodland to black willow and a few other fast-growing species that can regenerate after flood devastation. A Pleistocene flood regime that featured less flashy discharge would probably promote a flattening of all these curves.

The pre-inundation vegetation survey for Coleto Creek Reservoir (Espey, Huston and Associates 1976:Tables 2-2 to 2-6 and 2-15 to 2-17) shows the following results:

“bottomland forest” (actually wooded terrace)	31 taxa
“brushland”	48-60 taxa
“grassland”	45-47 taxa

Some of this information has already been reproduced in Tables 1.6 and 1.7 of the present study (which, however, omit "zero coverage" taxa). Although true mesic

floodplain is not represented in the Espey Huston study, it is clear that the grassland and brushland habitats actually have more plant taxa than the wooded terrace due to the addition of many more kinds of forbs. The most diverse sample, with 60 taxa, was recorded in springtime.

This brief survey suggests that whether floodplain environments are truly more productive and vegetatively diverse than uplands depends on *landscape context* and *season*. A wooded floodplain embedded in a wooded or scrub brush upland landscape might have slightly greater productivity and species richness than the upland forest, especially if it lies in a subhumid to semiarid climatic region where the upland woodland depends on precipitation, but the floodplain woodland is subsidized by runoff. In the dry season, even the minimal amount of stream base flow supplying the floodplain forest might give it an advantage by maintaining the floodplain water table.

On the other hand, where a floodplain gallery woodland is embedded in a prairie upland, the upland prairie might be expected to have a much higher diversity of plants, chiefly forbs, especially in springtime. Primary productivity would probably also fluctuate much more from season to season in an upland prairie.

All of the foregoing has concerned primary productivity — that is, plants. What about higher trophic levels? For small mammals, the Espey Huston baseline study produced the following results (Espey, Huston and Associates 1976:Table 3-19):

	Number of small mammals trapped	Number of taxa
“lowland forest”	1	1
“upland forest”	1	1
“brush piles”	27	2
“brushy pasture”	19	4
“open pasture”	27	2

This is probably typical of small mammal trapping studies in general: rodents are most abundant where there is abundant ground cover and plenty of forage in the form of forbs and seed-producing grasses, and least abundant in closed-canopy woodland, where shade inhibits the growth of ground cover. In a study in Johnson County, riparian woodland had four species, upland juniper woodland had one species, and grassy upland areas had two to five species (Hanchey and Wilkins 1998:Table 1). A study at Fairfield Lake in Freestone County produced these data (Wilkins and Broussard 2000:Table 1):

	Number of small mammals trapped	Number of taxa
Creekbottom forest	1.94	5
Marsh	7.73	4
Upland post oak forest	0.18	1
Pine forest	0.65	3
Grassland	0.64	3

In a study adjacent to Caddo Lake in Harrison County, four habitat types were studied: bottomland hardwood, sideslope hardwood, mixed slope pine-hardwood, and

upland pine. Bird diversity and abundance were greatest in bottomland hardwoods, but mammal diversity was greatest in upland pine, mammal abundance greatest in mixed pine-hardwood (Daniel and Fleet 1999).

In other environments, such as the Pacific Northwest, small mammal species richness, population size, and body weight may be greater in riparian than in upland areas (Doyle 1990). In trapping studies that might typically record only four to seven species of small mammals, the contrasts in species richness between riparian and upland habitats obviously will not be so great as for plants. A more significant pattern is for population sizes of some species to fluctuate dramatically from season to season or year to year (Grant, Carothers, and Gidley 1985).

By comparison, for some larger rivers of the southeastern US, Wharton and others (1981:Tables 4.13-4.16) list the following numbers of species:

	Small mammals	Amphibians/ reptiles
Chattahoochee R. (Georgia)	7	23
Alcovy R. (Georgia) pitfalls	7	12
Alcovy R. (Georgia) traps, etc.	-	18
Congaree Swamp (South Carolina)	-	30

Here we have no data for upland habitats, but the numbers at least suggest that most of the faunal diversity is expressed by amphibians and reptiles, rather than mammals. In some riparian ecosystems, amphibians and reptiles may outnumber birds and small mammals (Brode and Bury 1984). The following data on number of forest

herpetofauna species come from Harrison County, near Caddo Lake (Fleet and Autrey 1999:Table 1):

	Bottomland hardwoods	Slope hardwoods	Upslope pine-hardwoods	Upland pines
Salamander species	5	3	2	4
Anuran species	11	10	8	8
Turtle species	5	2	1	1
Lizard species	4	4	4	4
Snake species	13	16	13	11
TOTALS	38	35	28	28

Here, floodplain habitats clearly have more species richness than upland pine forests, because of the greater variety of anurans, turtles, and salamanders in bottomlands.

Snails have different habitat requirements from small mammals. Because they acquire body water mostly from food and minimally by drinking, most snails are highly susceptible to water loss and seek either mesic habitats or damper microhabitats that are embedded in dry habitats. While there are very few published snail censuses to consult, it is not surprising to find that riparian woodlands tend to have both larger populations and greater species richness than upland areas. A survey in Oklahoma and New Mexico by Wyckoff, Theler, and Carter (1997:Table 7) found an average of 6 species (range, 0-12) and a density of 1142 individuals/m² in riparian woodlands, compared to a mean of 2 (range, 0-6) and density of 280-310 individuals/m² on mesa tops, pastures, and plains. A survey by Logsdon (1967) in Kaufman County found 23, 10, and 4 taxa on the Trinity River, Brushy Creek, and Kings Creek floodplains, respectively. Abandoned fields,

pastures, and similar habitats had a range of 1-9 species, but typically about 3-5 species. I will have more to say about these studies in the chapter on the snail fauna.

If we return to the picture of coastal plain floodplains presented by Hall (1998) and ask, "Are floodplains more productive and biodiverse than uplands?" we must conclude the answer is, "It depends." It depends on whether we are talking about plants, small mammals, or snails. It depends on whether the floodplains are wooded, and whether grasses and forbs as well as trees, shrubs, and vines are to be inventoried. It depends on the season, especially where forbs, grasses, or rodents are concerned — for seasonally migratory species (birds) or animals with high fecundity and short lifespans, both abundance and diversity will vary by season. It depends on whether wooded floodplains are embedded in upland prairies or in upland woodland. And it depends on whether the prevailing climatic regime is moisture-deficient (so that any upland vegetation is heavily influenced by precipitation rates) or has a moisture surplus, and whether riparian woodland is subsidized by base flow that is maintained by groundwater discharge, or is sustained only on runoff from precipitation events.

GRAIN-SIZE ANALYSIS OF SEDIMENTS

THE PHI SCALE

Grain-size analysis uses the Wentworth scale of size grades. This is a logarithmic scale in which each successively larger size grade is exactly twice as large as the preceding grade. Size grades are expressed in terms of the *phi* (ϕ) scale instead of millimeters, and since the phi scale is logarithmic, grades coarser than 0.0 phi (*coarse*

sand) take on increasingly negative values, while grades finer than 0.0 phi take on increasingly positive values (Krumbein 1936). Phi is defined as

$$\phi = -\log_2 X$$

where X is the grade limit in millimeters.

All of the gravel grades have negative values, and the higher the negative value, the coarser the gravel (and this is why grades will always be written here as "1 to 2 phi" rather than "1-2 phi"). Inspection of Table 4.1 should clarify this for the reader. Analysis of the Berger Bluff samples was done in 0.5 phi intervals, and by convention, the coarser grades appear on the left side of the X axis in the histograms. *Silt* is sediment (usually fine-grained quartz particles) finer than 4.0 phi, or 0.0625 mm. *Clay* has been defined many ways in scientific usage; here it is defined as sediment finer than 8.0 phi (0.0039 mm in size). This is a *geological* definition of clay (Krumbein and Sloss 1963:Table 4-1; Folk 1980:24) and I have followed the geological definition in dealing with Berger Bluff sediments, which have little evidence of pedological alteration. In soil science, the definition differs slightly. For example, Birkeland (1984:Table 1-3) defines clay as particles finer than 0.002 mm and silt as finer than 0.02 mm. These are *pedological* definitions of silt and clay, as followed by the USDA, and, presumably, all soil labs that do textural analyses. Sediments analyzed here generally range between -2.5 phi and >9.0 phi, comprising 23 separate measured grades at 0.5 phi intervals.

Table 4.1. Wentworth Size Grades for Bench Sediments.

Phi value	Millimeters	Size grade	Analysis method
Held on:	Held on:		
-2.5 Φ	5.66 mm	N/A*	N/A*
-2.0	4.00	pebble	sieve
-1.5	2.83	granule	sieve
-1.0	2.00	granule	sieve
-0.5	1.41	very coarse sand	sieve
0.0	1.00	very coarse sand	sieve
0.5	0.71	coarse sand	sieve
1.0	0.50	coarse sand	sieve
1.5	0.35	medium sand	sieve
2.0	0.25	medium sand	sieve
2.5	0.177	fine sand	sieve
3.0	0.125	fine sand	sieve
3.5	0.088	very fine sand	sieve
4.0	0.0625	very fine sand	sieve
4.5	0.044	coarse silt	pipette
5.0	0.031	coarse silt	pipette
5.5	0.02210	medium silt	pipette
6.0	0.0156	medium silt	pipette
6.5	0.0110	fine silt	pipette
7.0	0.0078	fine silt	pipette
7.5	0.0055	very fine silt	pipette
8.0	0.0039	very fine silt	pipette
8.5	0.0028	clay	pipette
9.0	0.0020	clay	pipette
>9.0	not analyzed separately		

NOTE: "Held on" means that particular grade is held on a sieve with the specified mesh. For example, coarse sand between 0.5 phi and 1.0 phi is retained on the 1.0 phi sieve, and has diameters ranging between 0.50 mm and 0.71 mm. In other words, the size grade is named by its finer limit.

* Except for ro-tapped coarse gravels from N109 E96, all bench sediments analyzed were finer than -2.5 phi.

Sieve and pipette analysis

Because the bench sediments are heavily carbonate-cemented, the sediment samples (each about 15 g) had to be disaggregated in hydrochloric acid before analysis. Disaggregation was done very carefully to try to avoid digesting any clasts which themselves might have been of carbonate composition. Non-bench samples were not acid-digested. Gravel and sand-sized sediments were partitioned by dry sieving. Silt and clay-sized sediments were partitioned by pipette analysis. In this kind of analysis, a measured quantity of the sediment finer than 4.0 phi is blended in solution with distilled water and sodium hexametaphosphate (to deflocculate the clay particles), then allowed to settle in a glass cylinder, while 20 ml samples were drawn off by pipette at timed intervals. The size of the silt and clay particles is estimated with Stokes's Law of settling velocities. As time passes and the solution clears, successively finer particles of sediment are left in suspension. For clay particles, the process of drawing off successively finer samples at logarithmically greater time intervals could go on indefinitely. Since the time intervals increase exponentially, as a practical matter it is impossible to measure more than a few of the coarsest clay grades. In the present analysis, only the two coarsest clay grades (8.0 to 8.5 and 8.5 to 9.0 phi) were measured, since the last named requires eight hours and 10 minutes of settling time. An important implication is that all of the grain size histograms shown here essentially have undefined righthand tails. That is, the infinite number of finest clay grades could only be added together and reported as "clay finer than 9.0 phi". In practice, I have instead reported the 23 measured grades, plus totals for gravel, sand, silt, and clay. The actual lab procedure is considerably more complicated than portrayed here, but is detailed in the appendix on sediment analysis methods.

Grain-size statistics

Because the phi conversion translates the logarithmically scaled particle sizes to an arithmetic scale, the arithmetic mean, standard deviation, skewness, kurtosis, and coefficient of variation can be computed in conventional fashion (Krumbein 1936:39). Until the development of the personal computer, most geologists used less precise graphic but computationally simpler measures (in which *graphic means*, *graphic standard deviations*, and so forth are computed from cumulative curves; Folk 1980). These remain the most common measures seen in the literature, because grain-size analysis suddenly fell out of fashion at about the same time the personal computer arrived in the early 1980s to expedite the computations.

Grain-size statistics for the bench sediments have been computed by the method of moments, after Krumbein (1936) but with a few differences (see the grain-size appendix for details). The *mean grain size* is a measure of sediment fineness (higher positive values mean finer-grained sediment. The *standard deviation* is a measure of sorting (a smaller standard deviation means better sorting). The *coefficient of variation* is a measure of sorting that is independent of grain size. *Skewness* is a measure of departure from a normal distribution. Positively skewed samples have an excess of coarse grades and a long tail of fine grades, while negatively skewed samples have an excess of fine grades and a long tail of coarse grades. A normal distribution has a skewness of zero. All of the bench samples have negatively skewed distributions, while the upper deposits and two samples from the Lissie terrace cutbank have positively skewed distributions. In the field of statistics, there is actually a variety of formulas for computing skewness. The one used here is based on the difference between the mean and the median:

$$Sk = \frac{3(Xbar-Md)}{SD}$$

where Sk = skewness

Xbar = mean grain size

Md = median grain size

SD = standard deviation of grain size

A variety of statistics conceivably could be computed from the available grain-size data, but only the ones italicized in Table 4.2 are of concern here: the proportions of gravel, sand, silt, and clay; and the mean, standard deviation, skewness, and coefficient of variation, computed for all grades in a sample (maximum, 23 grades). The number of grades varies because some samples may not have gravel or coarse sand. Because the coarsest two clay grades (up to 9 ϕ) are included in the statistics, the statistics should be comparable to other analyses using the pedological definition of silt (coarser than 9 ϕ). ”All grades” means all gravel, sand, silt, and the two coarsest clay grades. When the proportions for the individual grades are added together, the sum typically amounts to about 60-80% for the bench samples. The remaining 20-40% represents the clay that remained in the water column after analysis was finished – the infinite tail of various clay grades that could not be analyzed because of excessive settling time. Thus, statistics like mean grain size necessarily disregard nearly all the clay in the sample, but at least the procedure is consistent across all the samples. For gravel, sand, silt, and clay *percentages*, the procedure is different. Here, all the proportions are recalculated so as to sum to 100% after carbonate is removed. After the gravel, sand, silt, and first two clay grades are added together, the difference between that sum and 100% is assumed to represent clay plus some small unknown amount of analytical error.

Table 4.2. Potential Grain-Size Statistics for Bench Sediments.

1. Mean, all grades
2. *Standard deviation, all grades*
3. *Skewness, all grades*
4. Kurtosis, all grades
5. *Coefficient of variation, all grades*
6. Mean, sand grades only
7. Standard deviation, sand grades only
8. Skewness, sand grades only
9. Kurtosis, sand grades only
10. Coefficient of variation, sand grades only
11. Mean, silt grades only
12. Standard deviation, silt grades only
13. Skewness, silt grades only
14. Kurtosis, silt grades only
15. Coefficient of variation, silt grades only
16. *Proportion of gravel*
17. *Proportion of sand*
18. *Proportion of silt*
19. Proportion of clay
20. Proportion of fines (silt+clay)
21. Sand/silt ratio
22. Sand/clay ratio
23. Silt/clay ratio

NOTE: This is a list of some possible statistics that could be computed using bench sediment data. The most important ones are italicized.

Transport modes: how they relate to sediment texture

Sediment coarseness is, for the most part, a measure of the amount of local energy in the fluvial system. Well-known laws of hydrodynamics define what discharge velocity is necessary to set a sediment particle in motion and keep it moving (Krumbein and Sloss 1963:197-203; Leopold, Wolman, and Miller 1964:169-180; Leopold 1994:191-197; Brown 1997:Appendix 1). Coarse sediment in channels moves by *traction*

(rolling or tumbling) along the bottom or by *saltation* (momentary rebounding above the bed, usually of somewhat smaller caliber particles), and fine sediment moves in *suspension* (fine particles kept aloft in the water column by turbidity). Much of the finest sediment load also moves in solution as *dissolved load* also, but we are not concerned with that here. These same processes — traction, saltation, and suspension — also apply when streamflow moves out of the channel and spreads over the floodplain in overbank floods, but unless the flow occupies a new or pre-existing channel across the floodplain, the first two processes are not likely to be important far beyond the channel bank. Instead, coarse sediments are likely to remain concentrated near the channel as levee, crevasse splay, or chute bar deposits, in most cases. Deposition from suspension is usually the dominant process for overbank flooding, *provided* the flood is sufficiently prolonged. Deposition occurs in still or stilling waters. When an overbank flow encounters a heavily vegetated floodplain (such as the floodplain of Coleto Creek when the bench sediments were accumulating), the flow may initially change from laminar to turbulent, which actually prevents deposition, but with further penetration into the floodplain, the flow is soon stilled, providing the opportunity for fine sediment to drop out of suspension. Later in this chapter, I will discuss patterns of deposition transverse to the channel axis in much more detail, and will show that stream scale, vegetation, and duration of flooding are important variables.

The clay component of the suspended load in streams draining this region is chiefly montmorillonite. Clays in suspended load samples collected from the Guadalupe River at Nursery contained 74-82% montmorillonite, with the remainder kaolinite and illite (Sorenson 1975).

> A clay particle of diameter 0.0001 mm settles 0.0001 cm/sec, which is 1 foot in about 3 days. A silt particle with diameter 0.02 mm settles 0.04 cm/sec, which is 1 foot in 10 minutes (Krumbein and Sloss 1963:197).

Because clay minerals form thin, platelike particles, deposition even in very still water is a slow process. Some quartz grains may even occur in clay-sized grades as well (Leschak and Ferrell 1988). Even under laboratory conditions (deionized water, dispersant, and absolutely still solution), it takes the coarsest grade of clay eight hours to settle 10 cm. Clay deposition, then, is likely to occur naturally only in closed depressions or in very prolonged, stilled floodwaters that persist for many days. As documented in Chapter 1 (Figs. 1.41 through 1.45), such conditions are absent in contemporary Coleto Creek, except for relatively small closed depressions or vegetated creek backwaters. In my excursions up and down Coleto Creek over the past two decades, I have seen no clay drapes on floodplain sediments except in closed depressions. Farther downstream, Morton and McGowen (1980:43) report that "mud deposits are usually destroyed by desiccation and aeolian erosion. Rare occurrences of thick, homogeneous mud or a mixture of mud and gravel are concentrated in lenses within chutes and along channel margins." For larger streams, at least, more sediment is actually transported as suspended load than as bedload (see Leopold 1994:Figs. 11.9-11.11). Limited studies appear to show that the Guadalupe River carries a greater suspended load than bedload, by about an order of magnitude (Holley 1992:Table 3.8.6). In that study, bedload is defined as sediment between about -3.0 ϕ and +3.0 ϕ (pebbles to fine sand; Holley 1992:Table 3.8.7), while suspended load is defined somewhat arbitrarily as about 4.0 to 9.0 ϕ (silt and coarse clay; Holley 1992:Table 3.8.5). According to Gomez (1991:89), “bedload will rarely include sediment that is finer than 01.-0.2 mm in diameter [about 2.25 to 3.25 Φ], because once disturbed these particle sizes go directly into suspension.”

There is, of course, a rough correspondence between grain size and transport mode. Generally speaking, gravel moves by traction, sand by traction and saltation; clay, silt, and the very finest grades of sand move in suspension. The size grades found in a deposit may give some idea of the transport history. Visher (1969) attempted to deduce different transport mechanisms from the size spectrum. He suggests that for fluvial sediments, 1) the traction load is coarser than about 1.0 ϕ, 2) the saltation load ranges from about 1.75 to 2.5 ϕ, 3) the lower limit of the suspension load ranges from about 2.75 to 3.5 ϕ (Visher 1969:1093). Presumably, the gaps between these ranges represent mixed processes. Ashley (1978:Fig. 3) places the upper boundary of traction at about 2 ϕ.

Other factors, such as *grain size inheritance*, may influence grain size. A well-known study by Folk and Ward (1957) of a Brazos River gravel bar in Milam County showed that the grain-size spectrum in the bar was determined mostly by the parent material supplying the sand and gravel upstream, and that variations in flow did little to redistribute the components in the bar itself.

Polymodal sediments

There are some environments (sand beaches, dunes, and lake beds, for example) characterized by well-sorted sediments (a limited range of size grades). More often, though, samples may contain distinct subpopulations of sand, silt, and clay (see Ashley 1978:Fig. 6). *Polymodal* samples like this might, therefore, represent a variety of different transport modes, or they might simply represent:

1. mixtures of different grades carried in turbulent water, deposited rapidly without sorting;

2. small-scale graded beds (coarse material at the base, fining upward) that represent waning streamflow, mixed by bioturbation long after deposition;

3. coarser, porous sediments later infiltrated by silt or clay carried either by groundwater or percolating rainwater.

In the last case, the coarse sediment might document the original transport mode, while infiltrated clay represents soil-forming processes.

Nearly all the bench sediment samples show some degree of polymodality. Figure 4.2 is a hypothetical example to show how the grain-size modes might relate to the mean, standard deviation, and possible transport modes.

Parsing these subpopulations into the components contributed by different transport modes is a worthwhile goal, but perhaps an intractable one. Ashley (1978) tries to do it using a graphical method advocated by Harding (1949). Harding's method, developed for biological material, involves creating a lognormal plot on probability paper, modeling the subpopulations as normal distributions. A simpler compromise might be to compute separate statistics for the arbitrarily defined sand and silt fractions.

Grain-size statistics: how they relate to transport mode

The *mean grain size* is a measure of the caliber of the sediment, and therefore of the amount of energy in the fluvial system, all other factors (such as grain size inheritance, or diagenesis) being equal. Since it incorporates all of the measured grades, in most cases the mean does not coincide with the most prominent grain-size mode, and since most bench samples are chiefly sand, the mean is in large part a measure of sand

fineness and abundance (Fig. 4.2).

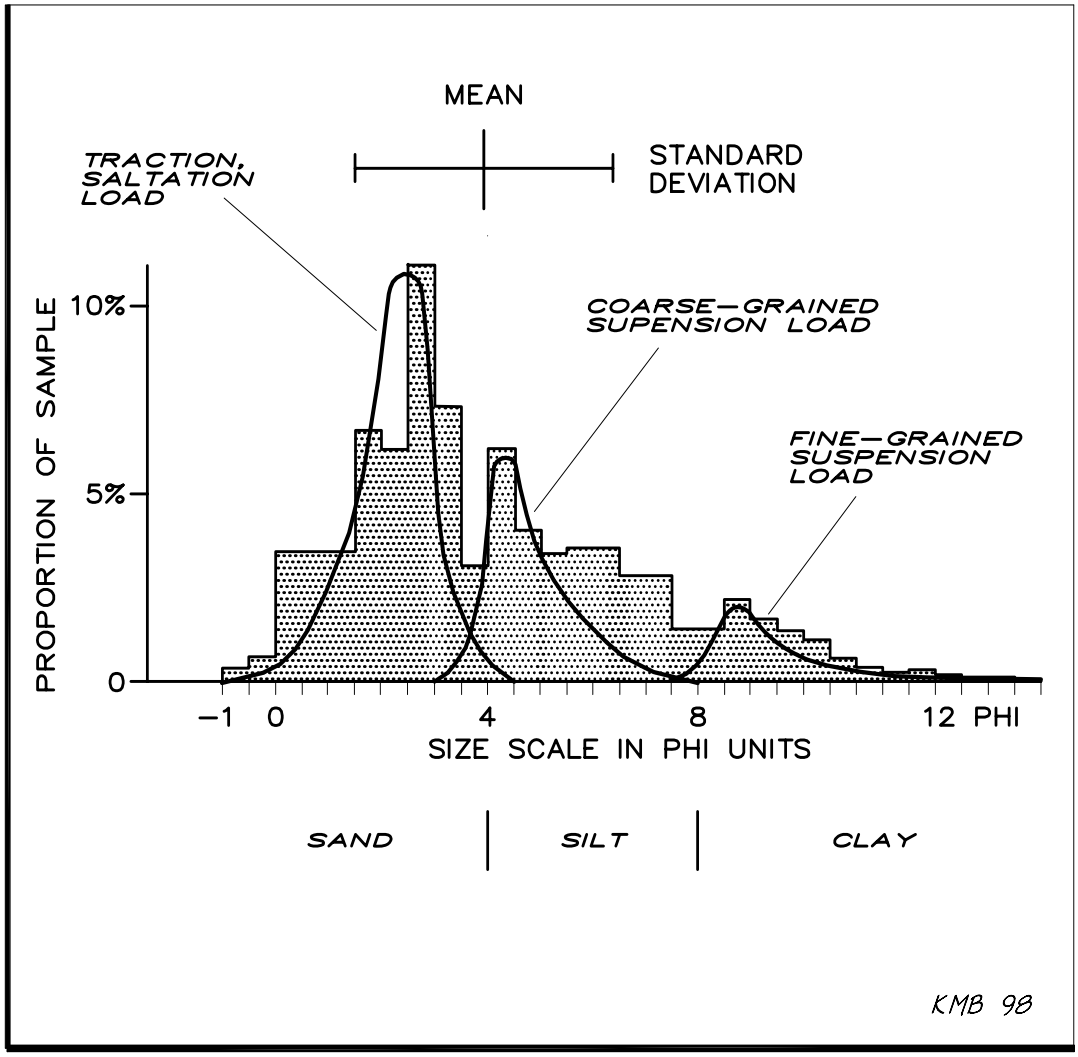


Figure 4.2. Grain-Size Distribution of a Hypothetical Sample. This imaginary sample is polymodal and shows what the clay fraction might look like if a more detailed analysis were possible. Superimposed curves suggest different transport modes. Areas where tails of curves overlap show some sediment grades may be transported more than one way. The plotted mean and standard deviation are not ideal statistics for polymodal samples, and are biased toward the sand fraction.

The *standard deviation* and *coefficient of variation* are measures of sorting, which in large part may be influenced by the degree of separation between different subpopulations (sand, silt, clay; or traction and suspension loads). Ashley (1978:411) says flatly that "statistical measures (such as skewness and kurtosis) simply reflect the relative magnitude and separation of populations." As a general rule, coarser-grained sediments are deposited more rapidly, with poorer sorting, and finer-grained sediments are deposited slowly with better sorting, so it is not surprising that plots of grain size against sorting usually show the two covarying in a quasi-linear way. Poor sorting and large standard deviations may suggest greater energy in the fluvial system.

Skewness is a measure of departure from the normal distribution. Because the bench sediments have long tails of silt and clay-sized fractions, all are negatively skewed. The degree of negative skewness is highly correlated with the mean grain size, so it does not add much to the characterization of the sediment. Samples with high negative skewness should indicate a larger proportion of deposition from suspension, and a lower level of energy in the fluvial system.

Grain-size analysis of Texas sediments and soils

A cursory review of the contract archeology literature shows that grain-size analysis has been used with increasing frequency in the last few years. I reviewed examples from the following counties: Titus, Hopkins, Rusk, Montague, Freestone, Leon, Chambers, Liberty, Harris, Grimes, Coryell, Concho, Coleman, Runnels, Tom Green, Kent, Garza, and Willacy. Many of these projects are in the Eocene sand belt of east and

east-central Texas, where archeologists have resorted to grain-size analysis to correlate excavations in thick, homogeneous sand sheets. Others are in the Rolling Plains, where analysis has been used to characterize profiles in river terraces.

Of the studies reviewed, about half are analyses at 0.5 ϕ intervals, with most of the rest at 1.0 ϕ intervals; a few have only percentages of gravel, sand, silt, and clay. Occasionally, analysis of fines was done by pipette (Nordt and Jacob 1995:160) or by pipette with centrifuging to extract clay (Mandel 1994:41), but far more commonly, samples were sent to a soils lab, usually at the University of Wisconsin-Milwaukee or Texas A&M University, where soil-science (rather than geological) methods have been used. This is probably appropriate where the chief interest is in defining paleosols, rather than sedimentary features. In these cases, analysis was usually by sieving of sand, with hydrometer analysis of silt and clay. In some cases, the size grades are defined as the pedological ones mentioned above by Birkeland, but in most cases the grades are not even defined. It is very rare to find any explicit statement of what constitutes clay. In some cases, sand was determined by sieving, clay by pipette, and silt was taken as the difference between the two. Vague allusions indicate that a few studies were apparently done in-house by CRM firms. A small number of studies report only gravel, sand, silt, and clay percentages.

The most common method of data reduction is to compute the standard deviation and mean grain size in phi units, although the method of computation is never explained. In cases where only the sand fraction is separated into size grades, these statistics are computed only for the sand component. One study (Rogers, Foster, and Reese-Taylor 1994:Appendix D) reports the graphic mean and standard deviation; the same study (page

66) says "this (*sic*) data is presented graphically in Chapter VII through histograms and logarithmic probability charts," but the promised plots are missing. A few others do use log probability plots. One (Skokan *et al*. 1997) makes extensive use of them, but does not use the straight-line segments plotted by Visher (1969). Occasionally stratigraphic plots of sand or clay percentages (Bousman 1992:Figs. 12, 13) or of grain-size means and standard deviations are used (Fields *et al*. 1991:Figs. 27, 49, 65, 78). This is the approach used for the Berger Bluff sediments.

The principal deficiencies in these studies are 1) failure to define grades, 2) failure to specify lab methods, 3) omission of analysis of fines, 4) omission of summary statistics, and 5) too many reports that simply list data tables, without stratigraphic plots.

MAGNETIC SUSCEPTIBILITY

Magnetic minerals

Magnetic susceptibility is determined by applying a temporary, artificial magnetic field to a small sediment sample, and is defined as the ratio of the magnetization induced in the sample to the strength of the applied field (Gale and Hoare 1991:202). Useful overviews can be found in Gale and Hoare (1991:201-229), Dalan and Banerjee (1998), and Maher (1998). The present study uses mass susceptibility (susceptibility normalized by the dry weight of the sediment sample). An inventory and details of sample preparation will be found in the appendix on magnetic susceptibility samples.

A wide variety of magnetizable iron oxide minerals can be found in sediments and soils: magnetite (Fe_3O_4), hematite (Fe_2O_3), maghemite (gamma Fe_2O_3), goethite (alpha FeOOH), lepidocrocite (gamma FeOOH), and others. The principal advantage of measuring susceptibility is that it can be determined quickly and cheaply, with small samples. In cases where enhanced susceptibility is associated with organic matter, the susceptibility signature may remain even where the organic matter has long since decayed away. The principal disadvantage is one of equifinality: susceptibility can be enhanced by more than one process, and very often it is not clear which process is responsible (see Maher 1998:Table 2). Firing of sediments can enhance susceptibility through the conversion of hematite to magnetite or maghemite (Ellwood *et al*. 1995), but there are no indications that firing has altered any of the bench area samples. There are indications of fire-building by the site's occupants (two documented hearths and occasional scattered bits of charcoal, fired clay, calcined bone, and heat-crazed chipping debris) but there are no prominent susceptibility peaks coinciding with these indicators, even where sample columns were collected less than a meter away from the known hearths.

The other processes known to be responsible for susceptibility enhancement of alluvium are pedogenesis and deposition of fine-grained magnetic material as part of the sediment suspended load (Oldfield 1992). Both processes appear at Berger Bluff: samples from the modern soil developed on the upper deposits show a typical pedogenic susceptibility profile, while sample columns from the bench sediments show susceptibility values that are highly correlated with the silt and clay content of the sample. Fine-grained magnetic minerals have been shown to be present in suspended load samples, yielding susceptibility values that are greater than those of gleyed soils, but

smaller than those of woodland topsoil (Walling *et al*. 1979:Table 1). These minerals may have been created elsewhere as a result of pedogenesis elsewhere, then redeposited along with the associated silt and clay as soils upstream were eroded. In the extensively studied deposits of the Chinese loess plateau, both the susceptibility and coefficient of frequency dependence increase as size grades become finer, peaking in the clay fraction — and this is true both for paleosols and the interbedded unaltered zones (Zheng *et al*. 1991:Fig. 1). Apparently, then, the clay fraction is strongly associated with enhanced magnetic susceptibility, regardless of the transport mechanism.

Susceptible minerals can also be created *in situ* in sediments by pedogenesis. Authigenic ultrafine-grained magnetite can be formed by soil weathering (Maher and Taylor 1988; Dearing *et al*. 1996). In such cases, the vertical distribution of the susceptibility values shows a typical "A horizon bulge" (Gale and Hoare 1991:Fig. 4.29; Maher and Taylor 1988:Fig. 2) in which the values peak just below the surface, then taper off into the B and C horizons. This trend parallels the typical vertical distribution of organic carbon as well. Susceptibility samples from the upper deposits at Berger Bluff show this kind of profile, tapering off to a minimum at about 1.5 m below the ground surface. The values are also conspicuously higher than those from the bench sediments, which are carbon-depleted.

According to Maher,

> Pedogenic formation of ferrimagnets appears to be favoured in well drained, not very acidic soils (pH ~5.5-7), on weatherable, Fe-bearing (but often *not* Fe-rich) substrates. The amount of magnetic enhancement often shows little correlation with other soil parameters, with the exception of some positive correlation with soil organic carbon and cation exchange capacity. The minerals formed by enhancement are magnetite and, by subsequent oxidation, maghemite. Maghemite is thus a common component of enhanced soils; it is not formed directly, but as an

> alteration product of the original mixed Fe^{2+}/Fe^{3+} spinel, magnetite. Oxidation of the smallest magnetite grains to maghemite may promote their subsequent survival in the soil. Ultrafine magnetite may be dissolved even in non-reducing conditions, due to its structural Fe^{2+} content; in contrast, the Fe^{3+} oxides require reduction for their dissolution (Taylor, pers. commun.). This may explain the observed link between susceptibility enhancement and a seasonally wet/dry climate regime (Tite and Linington, 1975), with magnetite formation during periods of intermittent soil wetness and its oxidation to maghemite in subsequent dry periods (Maher 1998:47).

Citrate-bicarbonate-dithionite (CBD) treatment is often used for selective removal of the pedogenic magnetic component. Susceptibility is measured before and after treatment, and the difference is taken as the pedogenic signal.

Various iron oxides and amorphous manganese oxide compounds as well as magnetic minerals (chiefly magnetite) can also be synthesized by magnetotactic bacteria, either in aquatic or damp soil environments (Fassbinder, Stanjek, and Vali 1990; Maher 1998:28-31; Moskowitz, Frankel, and Bazylinski 1993; Mustoe 1981). The magnetosomes produced are about 40-120 nanometers (a billionth of a meter) long. Greigite may be produced in sulfidic brackish water environments (Mann *et al*. 1990).

Iron oxides can also be redistributed by either vadose or phreatic water. Waterlogged or gleyed soils tend to have low susceptibility values because reducing conditions dissolve magnetic minerals and keep them in solution. Gleyed soils tend to have low coefficients of frequency dependence (*Xfd*, see below) because fine-grained magnetic material is most easily dissolved (Gale and Hoare 1991:214). This may well be the cause of reduced susceptibility values in Stratum 1 of the bench deposits.

Iron deposition in illuvial horizons will raise susceptibility values, but not Xfd. Iron content in the bench sediments is variable and somewhat idiosyncratic from excavation unit to unit. Counts of ferromanganese nodules recovered from the 1/4" screen do not correlate well with the magnetic susceptibility profiles, possibly because they were not consistently saved.

Measures and units

For Berger Bluff, magnetic susceptibility is reported in *cgs* (centimeter / gram / second units; coulombs) units. Much of the literature elsewhere in the world, especially in Europe, is reported in *SI* (Système Internationale units; amperes per meter, tesla). The two systems can be reconciled by means of the equation

$$X_{cgs} = 4 \pi X_{SI}$$

where X is the *chi* value. The chi value, generally defined as the ratio of the magnetization induced to the strength of the applied field, is defined in practice as

$$X = (R*7.36)/W$$

where X = chi (in dimensionless units)

R = susceptibility reading (at low or high frequency)

W = sample weight in grams

The Berger Bluff samples were measured on a Bartington MS2 system at two frequencies: low frequency at 0.465 kHz and high frequency at 4.65 kHz. Thus, for each sample there is a low-frequency chi value (X_{lo}) and a high-frequency chi value (X_{hi}).

The *coefficient of frequency dependence (Xfd)* is a measure of the extent to which changing measurement frequency changes the reading, and it is also an indicator of very fine-grained magnetic material. It is defined as

$$Xfd = ((X_{lo} - X_{hi})*100)/ X_{lo}$$

BERGER BLUFF IN ITS IMMEDIATE GEOLOGIC SETTING

The following assessment of the site setting is based on

1. Identification by Charles Winker of terrace surfaces shown on the USGS Schroeder 7.5' sheet;
2. General observations made by Winker in his thesis (Winker 1979) and during a field trip to Berger Bluff (December 5, 1979);
3. My own observations and sampling of the cutbank near the site, including two stratigraphic sections in the Lissie Formation upstream from the site;
4. Observations, profiles, and sampling of backhoe trenches in and around Area B during the Coleto Creek Flume #3 project.

There are four major geologic units in the immediate vicinity of the site. Some of these are visible both as mappable surfaces (Table 4.3) and in natural or artificial exposures that could be examined during fieldwork, while others were not examined in section during our fieldwork and simply represent surfaces recognized on the USGS or

pre-construction topographic maps. From youngest to oldest, these are:

1. Post-Beaumont fill and surface (after Winker 1979; Pleistocene and Holocene); locally, I recognize an older *Upper post-Beaumont (pBU)* and a younger *Lower Post-Beaumont (pBL)*.

2. Beaumont surface (Pleistocene). The Beeville-Bay City Sheet of *the Geologic Atlas of Texas* (Barnes 1975) does not show the Beaumont Formation in the immediate area, but through more detailed mapping in the immediate area, Charles Winker has identified what appear to be remnants of Beaumont-age Coleto Creek terraces inset into the Lissie Formation both upstream and downstream from Berger Bluff (Figs. 4.3-4.5)

3. Lissie Formation fill and surface (Pleistocene).

4. Goliad Formation bedrock (Miocene or Miocene/Pliocene) and surface [mapped as "pre-Lissie surfaces" by Winker (1979:Table 3)]

In addition to these, there at least two different sets of large meander scarps on the east side of the creek. These are of unknown antiquity (marked U for "unknown" on Fig. 4.3), but truncate Beaumont and upper post-Beaumont surfaces.

The ravine and Goliad Formation bedrock

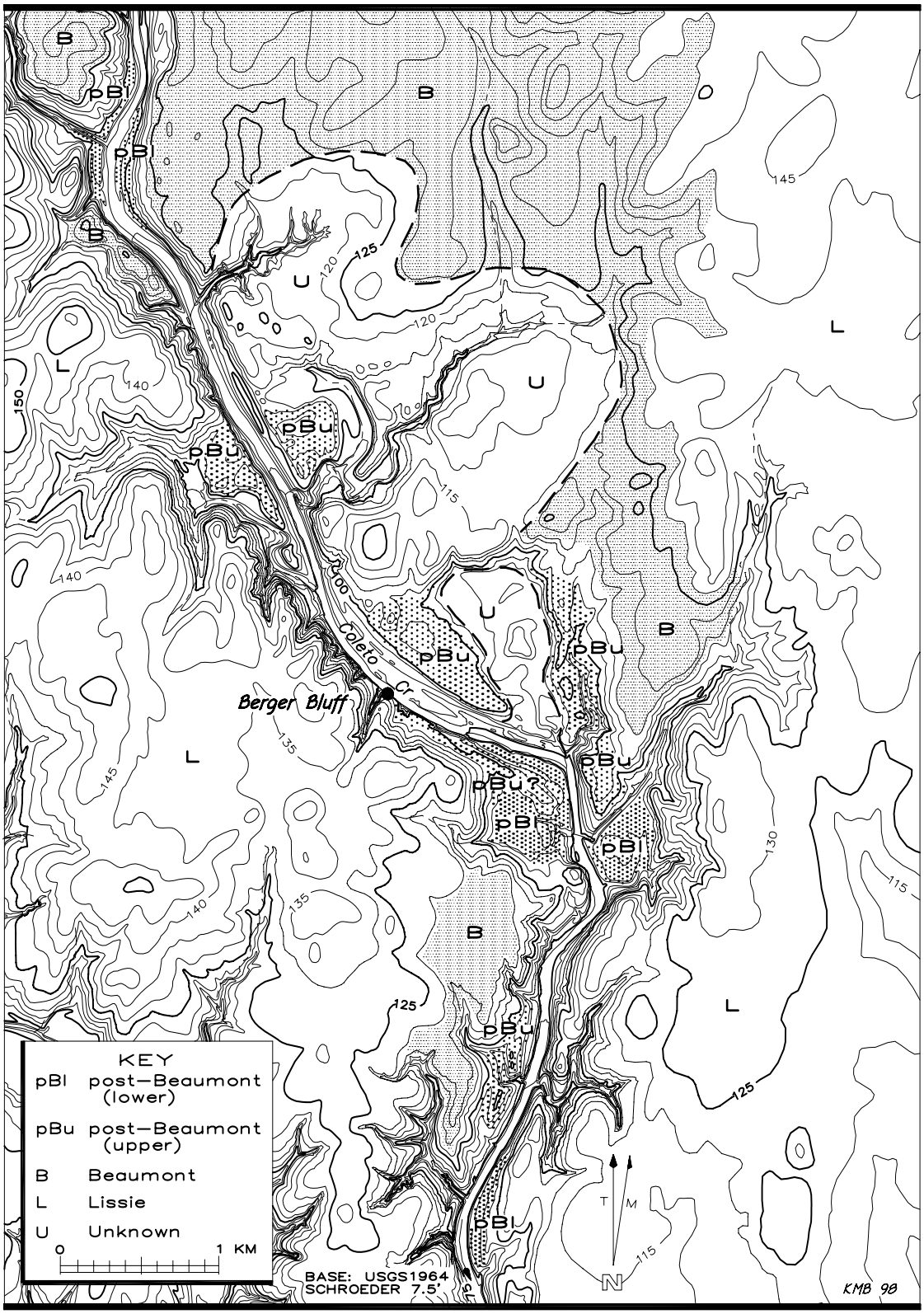
Immediately west of the site, and forming its western boundary, a long, relatively straight, deeply incised ravine cuts north-northeastward into the Lissie terrace sediments and joins the creek normal to its southern edge (Figs. 1.30, 4.3, 4.8). In the surrounding countryside, Winker has identified a couple of southwest-northeast trending low fault scarps (Fig. 1.25) that separate Lissie and pre-Lissie sediments. The ravine is not exactly parallel to these, but it is fairly linear, suggesting it might have originated as some sort of stress feature of Quaternary age. This is speculative, however, since there is no physical evidence of displacement or fracturing in the ravine.

Table 4.3. Terrace Heights, USGS Schroeder Quad.

	Mean	Standard deviation	Range	Number of terraces tallied
post-Beaumont (lower)	10.8 ft 3.30 m	3.4 ft 1.05 m	5-15 ft 1.5-4.6 m	6
post-Beaumont (upper)	20.4 ft 6.22 m	3.2 ft 0.98 m	15-25 ft 4.6-7.6 m	12
Unknown	25 ft, remnants at 35 ft 7.6 m, remnants at 10.7 m			N/A
Beaumont	40.0 ft 12.19 m	7.1 ft 2.16 m	30-50 ft 9.1-15.2 m	8
Lissie	about 65 ft about 19.81 m		40-70 ft 12.2-21.3 m	N/A
pre-Lissie (Goliad)	about 160-195 ft about 48.8-59.4 m			N/A

Source: USGS 7.5' Schroeder quad, terrace mapping by Charles Winker, modified by K. Brown; no field inspection except GD 30-31 area, and Lissie cutbank.

Figure 4.3 (following page). Immediate Geologic Context of Berger Bluff. Terrace surfaces as mapped by Charles Winker (personal communication, 1979) on part of the Schroeder quadrangle surrounding Berger Bluff. Contour interval is five feet. I have extended somewhat Winker's mapping of the post-Beaumont deposits and have divided this unit into two surfaces, upper and lower. Goliad Formation ("pre-Lissie") surfaces are just outside the limits of this map. Note large meander scarps of unknown age on northeast side of Coleto Creek. A simplified version of this map with topography deleted appears as the next figure.


KEY
pBl post–Beaumont (lower)
pBu post–Beaumont (upper)
B Beaumont
L Lissie
U Unknown
0 1 KM
BASE: USGS1964 SCHROEDER 7.5'
Berger Bluff
Coleto Cr.
T M
N
KMB 98

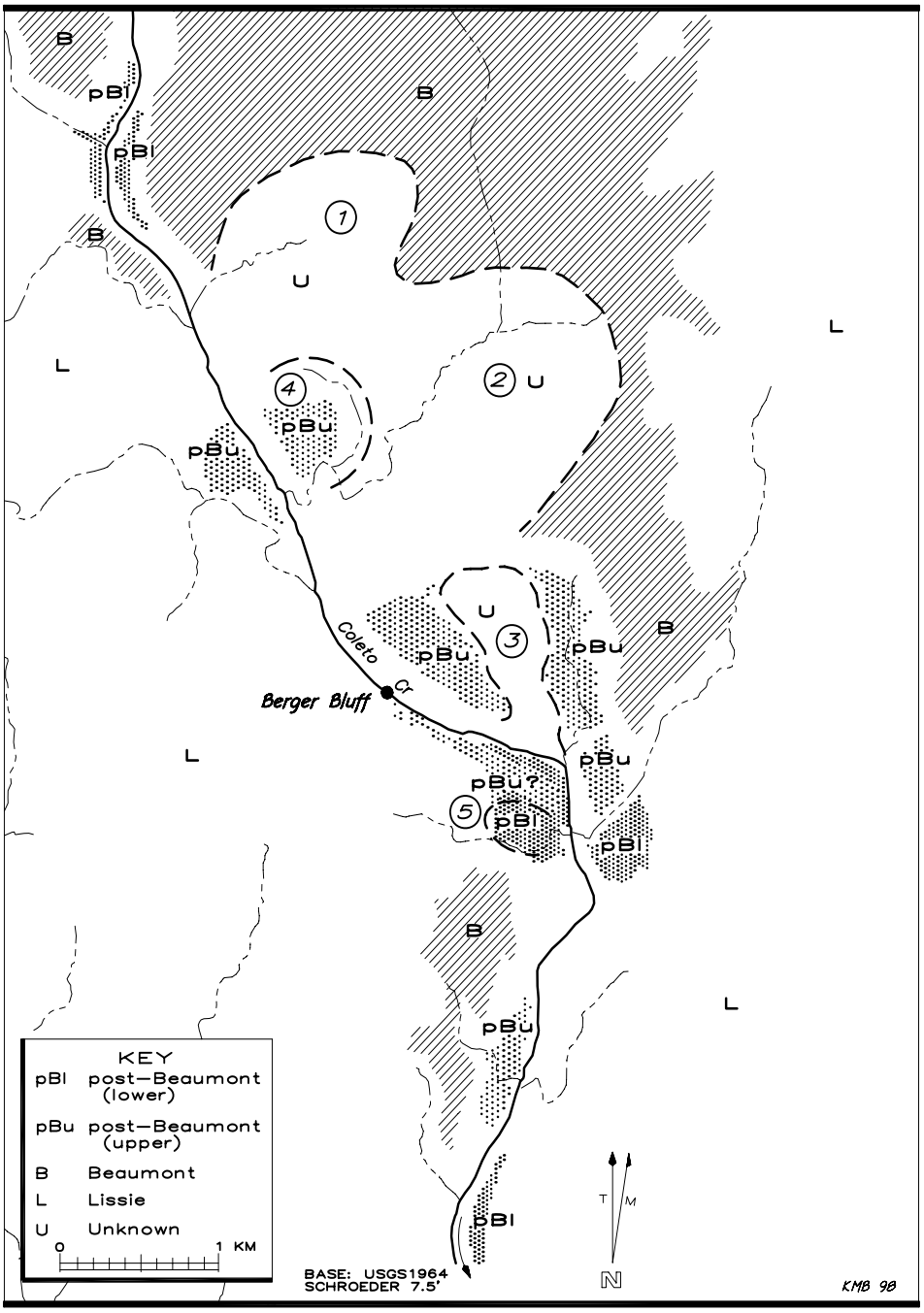


Figure 4.4. Simplified Map of Terrace Surfaces. This is Figure 4.3 with topography deleted to highlight the placement of different terrace surfaces and meander scarps (numbers 1-5).

Figure 4.5 (*following page*). Terraces on the Preiss Property. At the confluence of Fifteenmile Coleto and Twelvemile Coleto Creek (upper lefthand corner, Fig. 1.25), these units are tentatively identified: B = Beaumont (?) age Coleto Creek terrace; pBU = upper (?) post-Beaumont terrace; hatched area = lower (?) post-Beaumont terrace; 20, 21 = sampling localities for diatoms and snails; G = gravel scatter (Fig. 4.6); DS = drift snail sample; quarry symbol = gravel quarries, probably in veneer of Pliocene Willis Formation capping Goliad Formation bedrock. Mapping is tentative, based only on brief surface inspection. Contour interval is five feet; north is at top of page. Road along right side of map is Camp Coleto Road south of the creek, Arnold Road north of it. Source: USGS 7.5' Schroeder quad (1964 edition).

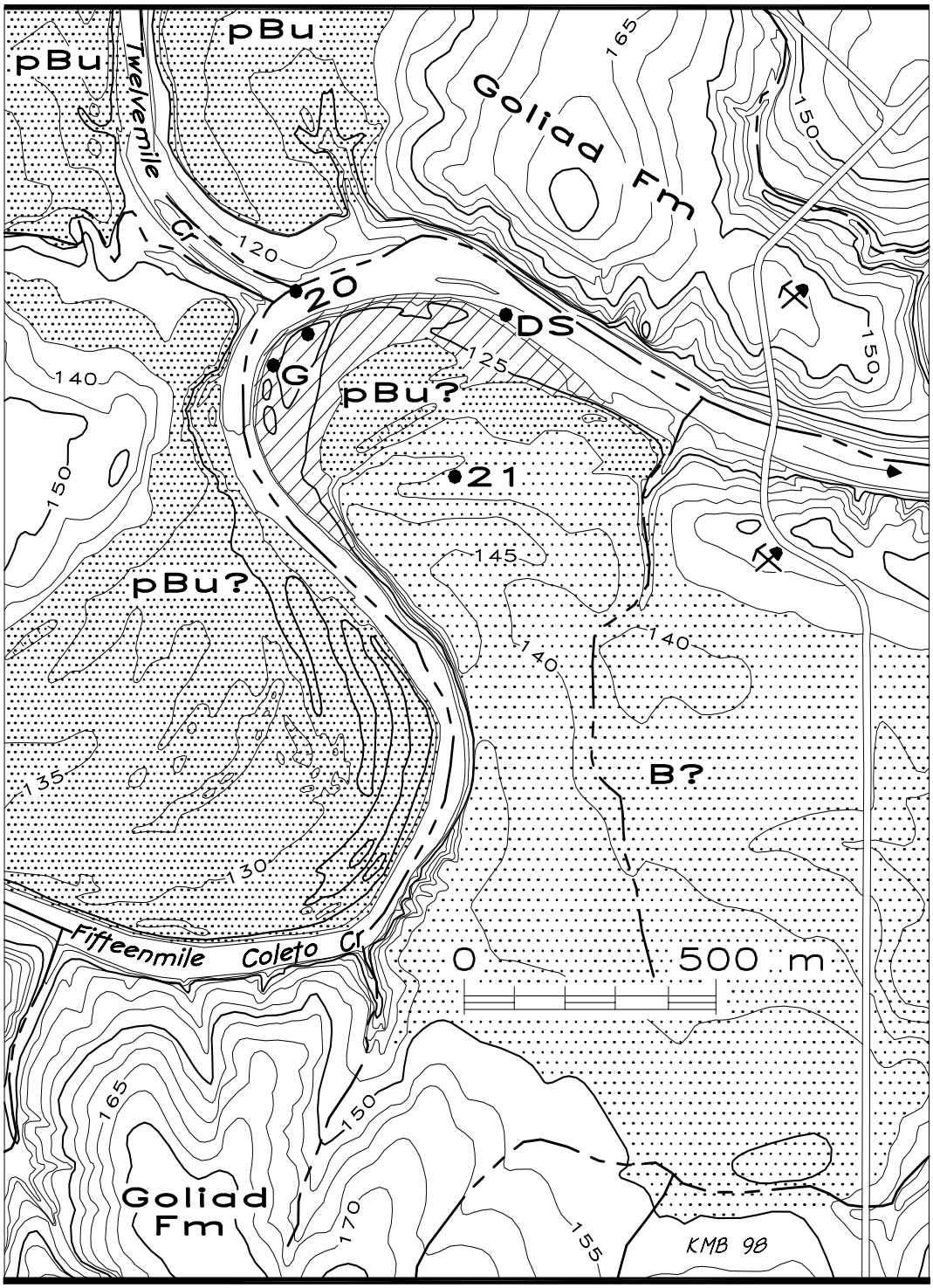

pBu
pBu
Twelvemile Cr
Goliad Fm
165
150
120
20
DS
G
125
140
150
pBu?
21
145
pBu?
140
140
B?
135
130
Fifteenmile Coleto Cr
0 500 m
165
150
Goliad Fm
170
155
KMB 98

Figure 4.6. Gravel Deposit on the Lower (?) Post-Beaumont Terrace. Looking south-southeast at gravel in shallow scour atop terrace on Preiss Ranch, near confluence of Twelvemile and Fifteenmile Coleto Creek. Photo November 18, 1998, shortly after flood.

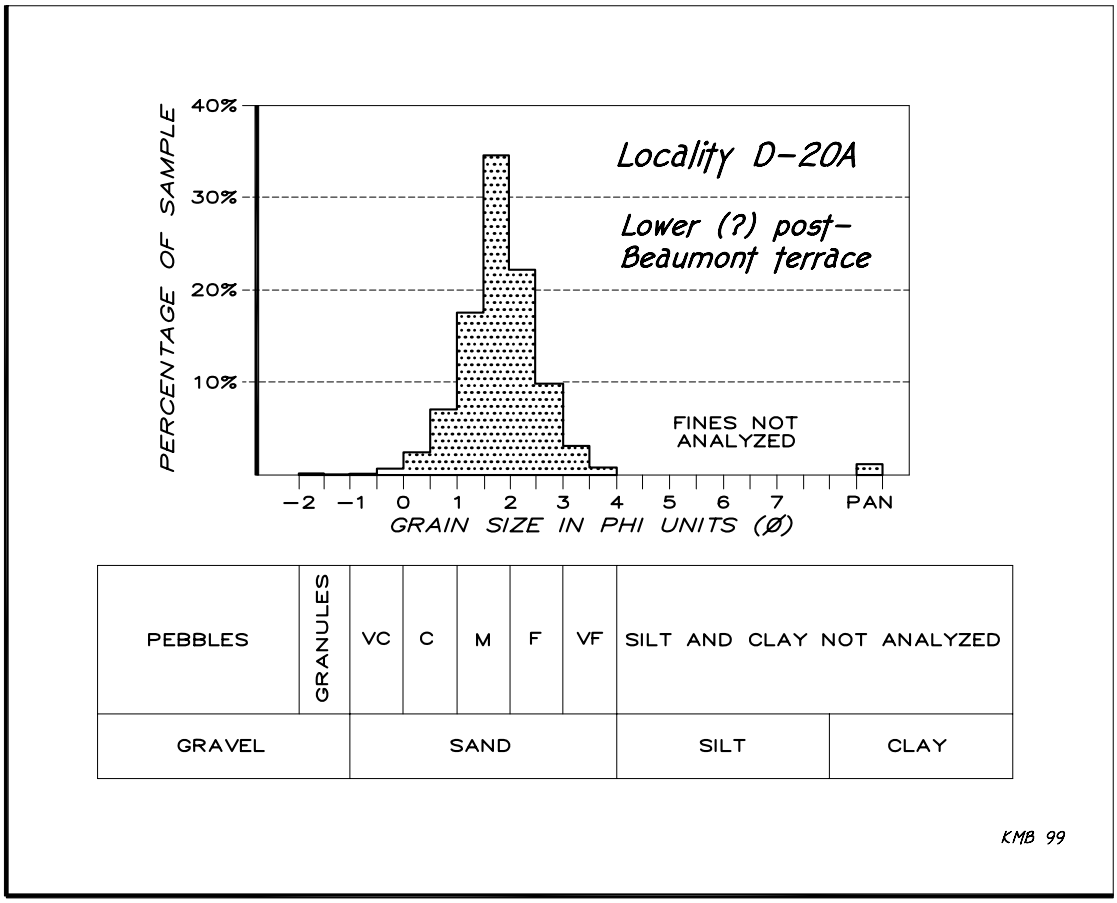


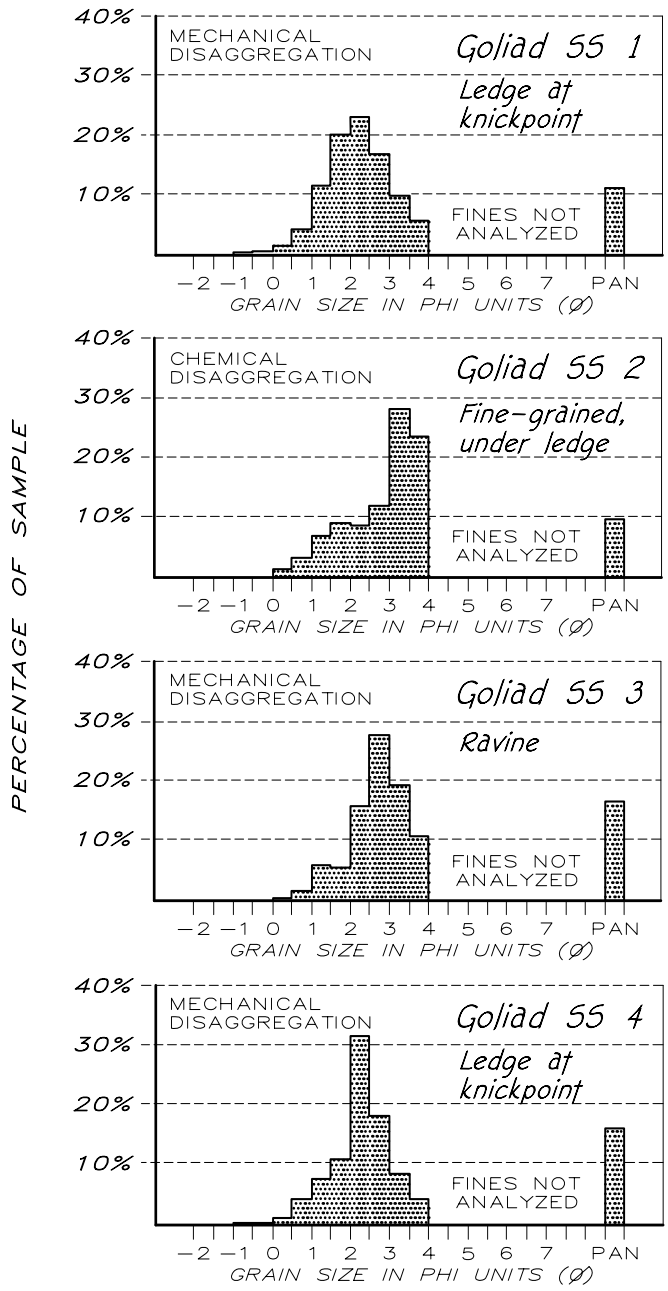
Figure 4.7. Grain-Size Histogram for Lower (?) Post-Beaumont Terrace. This sample was collected 2-4 cm below the surface of the terrace, about 3.75 m above the current water level, at diatom sampling locality D-20A, on the Preiss property, Goliad County (southernmost dot marked "20" on Figure 4.5). None of the gravel shown in Figure 4.6 occurred where this sample was collected. The histogram shows gravel and sand-sized components only; fines ("pan" fraction, shown at right) were weighed but not analyzed. Grain size is measured (in phi units) on the Wentworth scale, shown at the bottom.

Figure 4.8. The Ravine. Looking south-southwest toward the head of the ravine, from the eroded post-Beaumont surface (1977 testing phase). Area B of Berger Bluff lies to the left. Exposed areas have thin veneer of Lissie Formation sediments over Goliad Formation bedrock.

The highly calcareous, sandy Goliad Formation (Miocene or Miocene/Pliocene; Baskin 1991) crops out over a large area of Goliad, DeWitt, and Victoria counties upstream from the site, and its downdip contact lies about a kilometer and a half up Coleto Creek (Geologic Atlas of Texas, Beeville-Bay City sheet). This is the northeastern end of what W. Armstrong Price termed the "Reynosa Plateau," and he observed that "the eastern margin of the plateau is formed...by a low, interrupted scarp...more or less constantly present, where the Reynosa Caliche dips eastward under the Lissie" (Price 1936:559). This scarp probably corresponds to the one identified by Winker. In the immediate vicinity of the site, the Goliad Formation lies very thinly buried by more recent deposits, but appears as sandstone ledges forming knickpoints in the floor of the ravine (Fig. 1.32). This rock is fine, well sorted, tabular bedded quartz sand (with modes at 2.0 to 2.5, 2.5 to 3.0, and 3.0 to 3.5 phi on the Wentworth scale) with well indurated, opaque, white carbonate cement (Fig. 4.9, 4.10). Fines (silt and clay-sized sediments) appear to be scarce and porosity is presumably high (see Arredondo and Thomann 1996:286. There are also strata of less well indurated, marl-like calcareous clays. A low knoll of white, caliche-like material appears, sectioned by the cutbank, between the ravine mouth and the bench area (Fig. 4.11); this is presumably part of the Goliad Formation, and here it is directly overlain by post-Beaumont sediments. Elsewhere, however, the Lissie Formation (Pleistocene) sediments immediately west and south of the site appear to represent a relatively thin mantle (thickening near the creek) overlying Goliad sandstone or marl bedrock. On the flat Lissie surface well to the south of the site, coring data suggest about 3-4 m of Lissie sediments overlie the Goliad, although the drilling logs (Flume 3 core data, URS Forrest and Cotton, Inc.) were recorded with engineering properties rather than geology in mind, and are hard to interpret. The Lissie sediments are deeply weathered and oxidized, reddish fine sand, silt, and clay with a thin

layer of Goliad Formation rubble or rip-up clasts overlying the contact in some places. The contact can be traced up the ravine, except where obscured by brush or slumped soil, and the contact rises headward somewhat more rapidly than the ravine floor. Small Goliad sandstone clasts were frequently encountered in the bench excavations, especially in the southernmost unit (N109 E96), suggesting that an exposed outcrop of sandstone probably existed to the south or southwest while the lower post-Beaumont sediments were accumulating.

Figure 4.9 (*following page*). Grain-Size Histograms for Goliad Sandstone Samples. Histograms show gravel and sand-sized components only; fines ("pan" fraction, shown at right) were weighed but not analyzed. Samples 1, 3, and 4 were disaggregated by gentle, mechanical maceration in a mortar; sample 2, a finer-grained unit, was digested in dilute HCl. All of these samples come from bedrock exposed in the ravine. Grain size is measured (in phi units) on the Wentworth scale, shown at the bottom.



KMB 98

PEBBLES	GRANULES	VC	C	M	F	VF	SILT AND CLAY NOT ANALYZED	
GRAVEL		SAND					SILT	CLAY

Figure 4.10. Goliad Sandstone Bedrock Outcrop. Looking east at tabular bedded Goliad sandstone in east wall of ravine; scale is 50 cm long. Photo taken December 9, 1979.

Figure 4.11. Goliad Formation Marl or Calcareous Clay. Looking southwest at light-colored Goliad Formation marl or calcareous clay overlain by post-Beaumont sediments; view from creek. Bench area lies out of view to left, ravine mouth out of view to right. Surface slopes down and topsoil thins to right because of erosion into the ravine. Photo taken November 8, 1979.

In most of the backhoe trenches dug in Area B (Brown 1986:Figs. 2, 4), indurated Goliad bedrock formed the floor of the trench and was reached at a depth of about 1.5-1.9 m. This sandstone varies from a friable, gritty rock to a hard, caliche-like, fine-grained rock. In general it closely resembles sandstone exposed in the floor of the ravine about 3 meters lower in elevation. Overlying the indurated bedrock is a caliche zone that is probably pedogenic in origin, although it may have developed not by downward transport of carbonate through the vadose zone, but rather by upward capillary movement of carbonate-laden water from underlying bedrock. In its purest form (backhoe trench 2, zone 2, sample 4) it is pure white, with a light, talc or diatomite-like

consistency and texture, with dry weight about 1.3 g/ml. Hand specimens contain no visible contaminants, but samples digested in HCl yield about 13% of fine and very fine sand (chiefly 2.0 to 3.0 phi). It occurs as massive, structureless deposits. In most of the trenches, however, the caliche occurs as discontinuous masses intermixed with calcareous tan fine sand and fragments of indurated white sandstone. The caliche unit is laterally rather variable in composition and thickness (ranging from about 40 to 125 cm thick). A rather compressed solum is developed on the caliche, becoming very organic-rich in areas covered by anaqua motts; the soil corresponds well to descriptions of Valco soils in Victoria County (Miller 1982:81-82). In an earlier publication (Brown 1986:12) the term *marl* was applied generally to unconsolidated Goliad deposits at this site, the chalklike unit exposed in the backhoe trenches is probably better regarded as a *caliche* of pedogenic origin. All of this caliche is restricted to the ridge south of area A, and nothing comparable is found in the bench deposits.

Although the deposits on the southwest side of the creek near the site are mostly mapped as Lissie Formation by the *Geologic Atlas*, this area represents the basal part of the Lissie, and where it has been truncated by erosion into Coleto Creek is really just a thin mantle of gravelly sand and orange sandy clay over the Goliad Formation, except immediately adjacent to Coleto Creek itself where it thickens to eight meters or more of valley fill. This dramatic thickening of the Lissie deposits along Coleto Creek is a clue that the drainage is probably quite old, evidently predating the Lissie Formation itself. Equally surprising, however, are indications that the small drainages entering the Coleto from the southwest might be just as old. The two-foot contour map of the Berger Bluff vicinity shows a striking contrast in the topography on the northeast and southwest sides of the creek. The topography on the southwest side is bedrock-dominated and is

deeply dissected by several ravines that are disposed at right angles to the trend of the creek. The topography on the other (Victoria County) side of the creek is flat and smooth by comparison and represents the nearly unmodified surface of a thick package of Holocene alluvial fill (Fig. 1.30). Hand testing of Berger Bluff in 1977 and 1979 and backhoe testing in 1983 (at Area B and south of it) has established that, away from the creek bluff, the Goliad Formation lies nearly everywhere just under the surface — in other words, the present topography on the Goliad County side of the creek seems to follow closely the subsurface configuration of the Goliad Formation. Inspection of utility pole borings and gullies near the site has helped to amplify the backhoe testing data and provide some idea of bedrock topography away from the site.

The information we have suggests the erosional events that produced the system of ravines draining northeast to the Coleto may not have originated within the Lissie Formation but perhaps predated it, since the Lissie thickens locally to follow the eroded surface of the Goliad Formation downward. This implies the bedrock-dominated topography on the southwest side of the creek is quite old. This picture of the bedrock geology has several implications for the archeological history of the site:

1. The bedrock channel of the ravine seems to have been present throughout the occupation of the site, and if not choked with sediment, probably has also been a functioning drainage as well;

2. Although now masked by post-Beaumont alluvium, the Goliad Formation probably lies a short distance southwest of the bench excavations and rises rapidly to an elevation of about 111 feet MSL (*ca*. 102.80 m in terms of the primary datum; Fig. 1.33) eighty meters back from the creek, forming what presumably would have been a steep, rocky hillside, perhaps with thin, unstable, poorly developed soil cover throughout the history of the site. This rocky hillside has been a constant source of clastic debris (sandstone and marl fragments) and possibly some colluvial sediment, especially during the early history of the site.

3. This large subsurface mass of highly calcareous sandstone and marl has furnished a constant source for calcium carbonate mobilized by groundwater and re-precipitated in the archeological deposits, especially the lower units.

4. The Goliad Formation bedrock has probably restricted lateral migration of Coleto Creek southward, although as noted above the only outcrop visible along the creek in 1979 was the small exposure of marl immediately upstream from the bench area.

The Evangeline aquifer

The Lissie Formation sediments in this area, although not indurated, are clearly finer grained than most of the Goliad Formation bedrock. This is probably because the Berger Bluff area was on the periphery of the Goliad age "Coleto" meanderbelt system, as defined by Solis I. (1981:Fig. 26), but by Lissie depositional time, was an interfluvial area distant from the main Guadalupe meanderbelt (Solis I. 1981:Fig. 29). The Goliad Formation sediments appear to be a local aquifer, presumably part of the regional Evangeline Aquifer, which also extends into the upper part of the Fleming Formation according to Baker (1979:40; Figs. 7, 8, 14) or else is separate from the Fleming aquifer (Snyder 1995). Perhaps this aquifer is partially confined by the finer grained overlying Lissie sediments; in any case, it seems to have been a local source of somewhat alkaline groundwater during the Pleistocene and the wetter parts of the Holocene. A small perennial spring pool, rimmed with cattails, lies in the bed of the ravine southwest of the site (Figs. 1.30, 1.31). Groundwater from the Evangeline aquifer in Bee County had a measured pH of 7.3 and temperature of 23.7º C (Snyder 1995:Table 3). The Goliad Formation is also a host for uranium mineralization (Hoel 1982), and groundwater from the Evangeline aquifer may carry trace amounts of uranium or radon. The uranium occurs as uraninite and as amorphous uranium (Arredondo and Thomann 1996). The most porous objects recovered from excavations in the bench sediments (mostly fired clay

nodules, but also including some animal bone) occasionally have a faint yellow tint that may represent some type of uranium oxide coating left by groundwater. Many of the uranium minerals have a yellow color, while uraninite is black, often with a steely luster. Many of the animal bones recovered from the bench deposits have patchy black to steely blue-black surface stains that have been interpreted as manganese, but could just as easily be uraninite. No mineralogical studies of these coatings have been done.

Lissie terrace sediments

Two stratigraphic sections were recorded for the Lissie terrace cutbank during fieldwork at Berger Bluff. Section #1 (Fig. 4.12) is located just upstream from the ravine bordering the site on the northwest. It is over 6 meters from top to bottom. The upper 3.5 m (Fig. 4.13) consist of gray sandy clay with well-developed soil structure and are probably post-Beaumont sediments resting on an eroded Lissie contact, although in the profile, the contact appears gradational rather than clearly erosional. Alternatively, the entire upper 6 m might be Lissie Formation. Possibly this could have been investigated by collecting an oriented sediment sample to check magnetic polarity, since much of the Lissie Formation probably accumulated during a period of reversed polarity, but no oriented samples were collected. Below these gray sediments are slightly rubified silty sediments with carbonate webbing and caliche nodules, evidence of fairly strong soil development. A sediment sample (1-1) at about 4.5 m was subsampled to allow Barbara Winsborough to check for diatoms (diatom sample 40). She found that the sample was barren of diatoms. At the base of section 1, a thin irregular layer of structureless, well-sorted, fine sand overlies the Goliad marl and may represent reworked sediment from the Goliad Formation (Fig. 4.13). Modal grain size of the sand is 2.5 to 3.0 phi, and it is

remarkably well sorted. A sediment sample (1-3) was subsampled to check for diatoms, and diatom sample 42 produced a small but interesting assemblage that differs significantly from that found in the bench sediments. Present were several marsh species (*Epithemia turgida, Denticula elegans, Fragilaria pinnata*, and *Opephora martyi*) that probably represented a resident population (Winsborough 1992). Indeed, the last two taxa are not represented at all in the bench sediments. *Fragilaria pinnata* prefers cool, well-oxygenated water. The other diatoms in the sample are mostly corroded and fragmented by reworking. Further details will be presented in the chapter on the diatom record.

The dust fraction from all of the Lissie sediment samples was checked microscopically for freshwater sponge spicules. None were seen in sample 1-1, occasional spicules were seen in sample 1-2, and in sample 1-3, very well preserved, complete or nearly complete spicules identical to those in the bench deposits were seen. In sample 1-4, only one possible spicule was noted. All of the freshwater sponge spicules (megascleres) seen so far are the same; the species is unknown, but they resemble illustrations of *Spongilla lacustris*, a common pond sponge. All of the spicules seen are oxeas with readily visible axial filaments, and they extinguish under polarized light, indicating they are made of isotropic silica.

Figure 4.12. Lissie Formation, View of Section 1. Looking south-southwest at Lissie terrace stratigraphic section 1, from the creek. Ravine mouth and Berger Bluff lie out of view to the left. Scale is 50 cm long. In the foreground are slumped blocks of clay-rich Lissie sediments. Photo taken March 10, 1980.

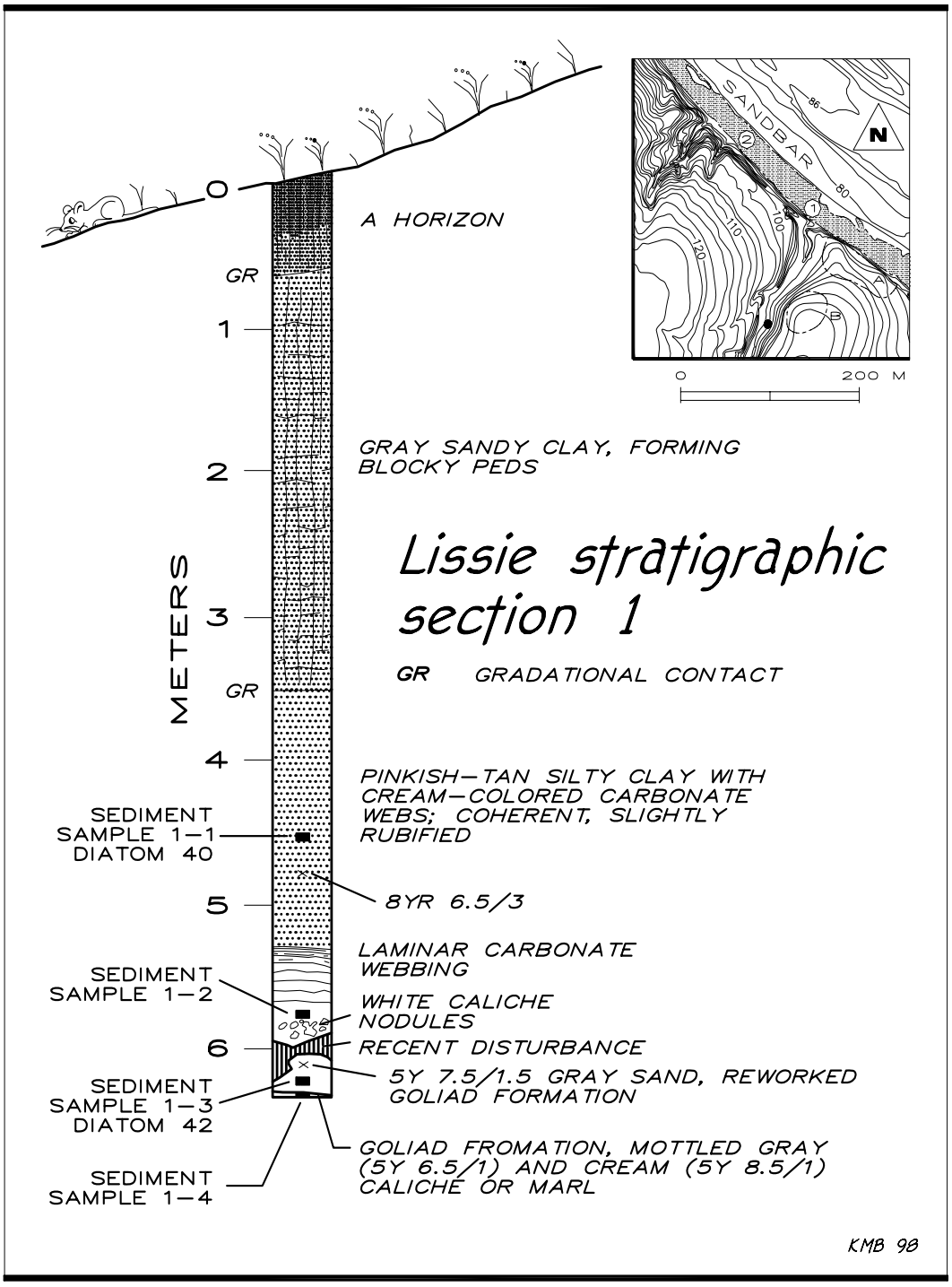


Figure 4.13. Lissie Formation, Measured Section 1. Four sediment samples were collected; grain-size was determined for samples 1-2 and 1-3 (see Fig. 4.16) and diatom subsamples were extracted from samples 1-1 and 1-3.

Section #2 is located an estimated 100 m farther upstream and is also about 6 meters thick, although it was recorded in two offset subsections. Fig. 4.14 shows just the upper part of the section. It is slightly higher both stratigraphically and in terms of absolute elevation than the first section. Iron content increases noticeably upstream and is considerably greater in this section. The A horizon is better developed and more sharply defined here (Fig. 4.15), approximately 80 cm thick, and immediately under it is a zone of intensely weathered, heavily rubified sediments. It appears as a brightly colored, mottled dark brown and orange unit with small ferromanganese concretions. This appears to be a well-developed oxic horizon (presumably a Bo or Bw horizon) indicating prolonged soil development, perhaps under well drained conditions with high temperatures. A grain size sample (2-1) from this unit contains about 4% gravel, 62% sand, 12% silt, and 22% clay (Fig. 4.16). The clay is either authigenic or translocated. Under the weathered zone is a transitional unit, then several meters of pinkish tan silty, clay-rich sand similar to that in the first section. A major horizon of abundant caliche nodules is located at about 6 to 7 meters below the surface, with scattered nodules and one minor band of nodules above that.

Only three sediment samples from the Lissie sediments have been analyzed for grain size, but they are consistent. The samples are over half sand (Table 4.4) with a primary size mode at 2.5 to 3.0 phi, and in one case a secondary mode at 1.5 to 2.0 phi. This is consistent with the coarser grained depositional units in the bench deposits (strata 1, 2B, 2D, and 2E, to be discussed later in this chapter). The extent to which these units may have inherited a grain size imprint from the Lissie sediments will be discussed later. All four sediment samples (2-1, 2-2, 2-3, and 2-4) were examined microscopically, but no

sponge spicules were seen.

Figure 4.14. Lissie Formation, View of Top of Section 2. Looking west at topmost part of Lissie terrace stratigraphic section 2, showing the uppermost two units, terrace surface at top of frame. Sample 2-1 was collected here. Scale is 50 cm long; photo taken March 10, 1980. Compare with figure 4.15.

Table 4.4. Grain-Size Statistics for Miscellaneous Samples.

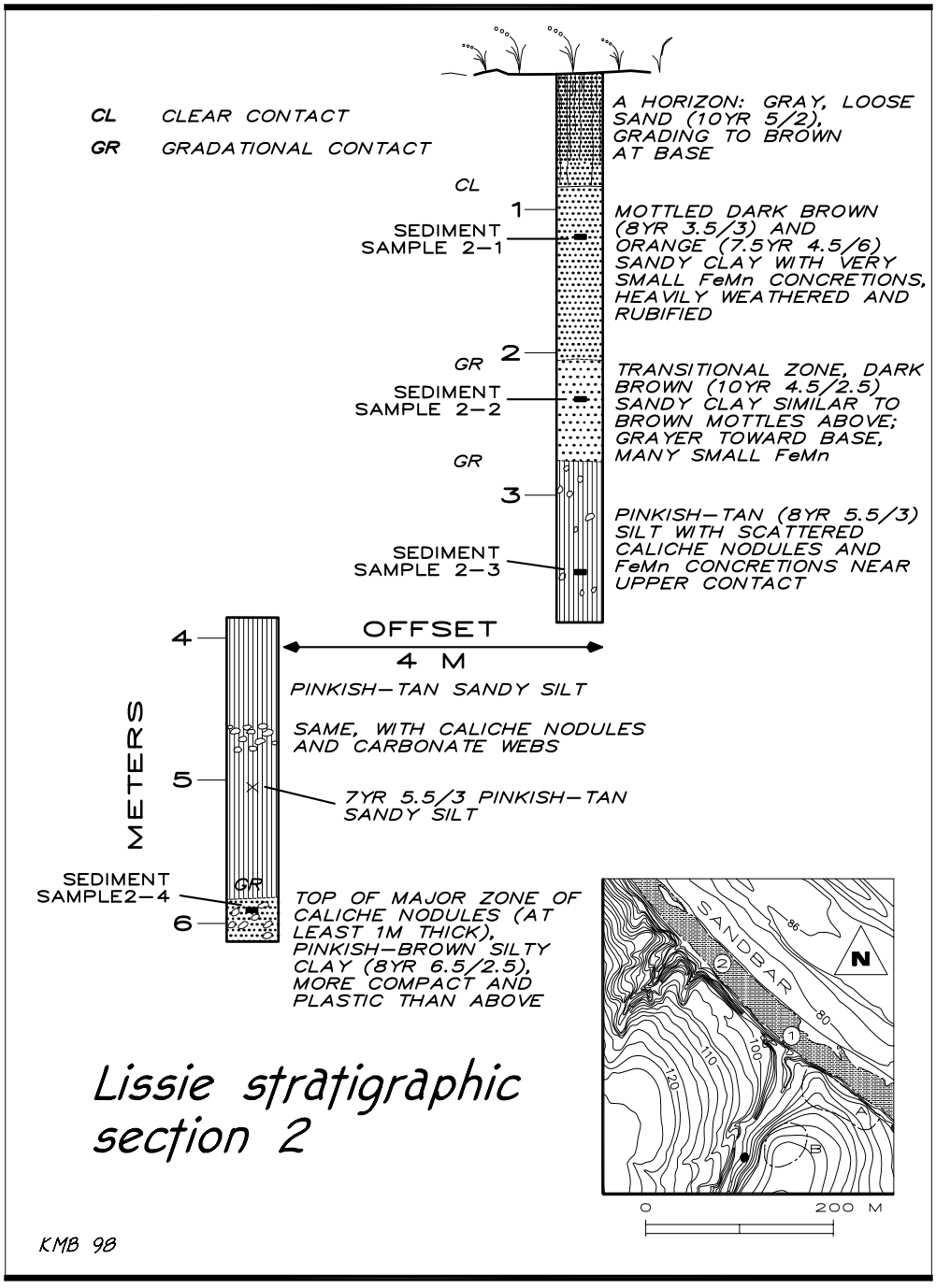
Sample	Mean Grain Size (Φ)	Standard deviation (Φ)	Skewness (unitless)	Coefficient of Variation	Gravel %	Sand %	Silt %	Clay %
Lissie terrace stratigraphic sections								
Lissie 2-1	2.64	2.22	-0.28	0.84	3.73	62.11	12.43	21.73
Lissie 1-2	3.92	1.80	+0.49	0.46	0	53.37	28.28	18.35
Lissie 1-3[1]	2.90	1.16	+0.38	0.40	0	83.22	8.54	8.24
Lower (?) post-Beaumont terrace, Preiss property, locality D-20A (gravel and sand only; fines not analyzed)								
D-20A	1.80	0.70	-0.05	0.39	0.15	98.59	N/A	N/A
N109 E96								
93.00-92.95[2]	4.08	2.53	-0.71	0.62	3.11	39.87	14.38	42.64
92.30-92.25	3.36	2.21	-0.22	0.66	0.65	52.51	21.81	25.03
92.15-92.10	4.96	1.95	-1.98	0.39	0.03	23.62	39.01	37.34
Cutbank, Stratum 2E (gravel and sand only; fines not analyzed)								
93.45-93.40[3]	1.11	1.74	-1.77	1.57	9.92	90.08	N/A	N/A
Cutbank, Stratum 2E								
93.40-93.35	2.83	2.39	-0.05	0.84	0.31	64.37	13.34	19.19

NOTE: Percentages and statistics are computed on a carbonate-free basis; statistics include the coarsest two clay grades (8.0 to 8.5 Φ and 8.5 to 9.0 Φ), but not the unanalyzed clay grades that are finer. The clay percentage includes an error component.

[1] Reworked Goliad sand.

[2] Extracted from pollen sample at 92.99-92.98 m; slight loss of sand and fines during lab processing. Includes chert pebbles in -3.0 to -2.5 Φ grade.

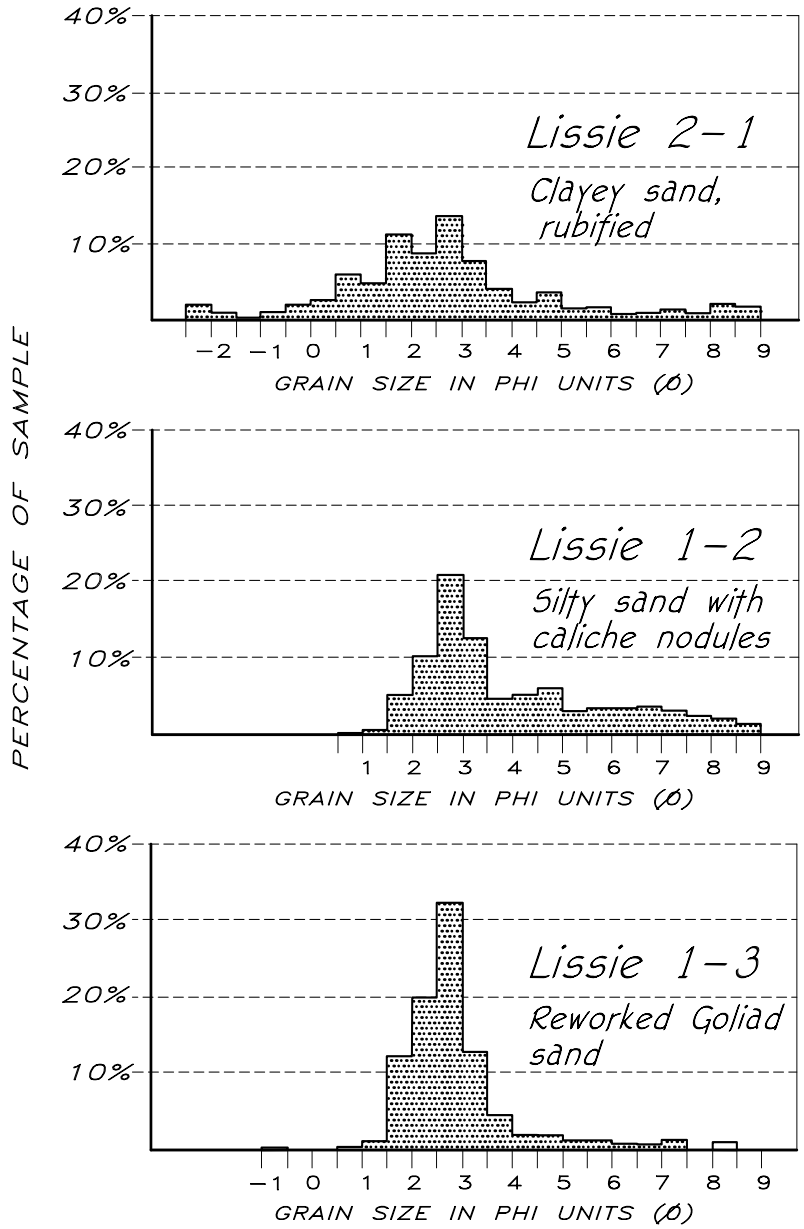
[3] Large (274.4 g) sample for gravel analysis; statistics were computed only for the 15 gravel and sand grades that were analyzed. Sample was disaggregated in acid.



Lissie stratigraphic section 2

Figure 4.15. Lissie Formation, Measured Section 2. Section was measured in two discontinuous, offset segments four meters apart. Inset shows location. See Fig. 4.16 for grain-size distribution of sample 2-1.

Figure 4.16 (*following page*). Grain-Size Histograms for Lissie Sediment Samples. Analysis by sieving of coarse fraction and pipette analysis of silt and clay fractions; only the coarsest two clay grades (8.0-8.5 and 8.5-9.0 phi) were determined individually. Grain size is measured (in phi units) on the Wentworth scale, shown at the bottom. Sample 1-3 is believed to be reworked Goliad sediment at the base of the Lissie Formation deposit.



PEBBLES	GRANULES	VC	C	M	F	VF	C	M	F	VF	COARSEST TWO CLAY GRADES ONLY
GRAVEL		SAND					SILT				CLAY

KMB 98

Because the Lissie Formation is perhaps the most likely candidate for contributing sediment to the bench deposits, the Lissie terrace cutbank was examined fairly carefully for biological material that could have been reworked into later deposits. No vertebrate remains, mussel shells, or snail shells were seen in this part of the cutbank, and the diatom assemblage clearly does not match that from the bench sediments. Only the freshwater sponge spicules concentrated in the reworked Goliad sand remain as potential contaminants.

Elevation of the Lissie terrace surface ranges up to about 150 feet above MSL away from the creek, but it has eroded to about 100 feet (30 m) elevation along the creek. Its average elevation above the creek bed is roughly 20 m (Table 4.3). The flat, sandy, well-drained Lissie surface has a distinctive, easily recognized cover of open post oak, blackjack, and live oak woodland where it has not been cleared for pasturage. A wide variety of soils is developed on the Lissie deposits, but in the area around the site, Straber loamy fine sand and Telferner fine sandy loam are most extensive (Miller 1982:sheets 21 and 26). These soils are slightly to moderately acid in the upper part of the solum.

The Lissie Formation is known to be Pleistocene, but as far as I know, there are no chronometric isotope assays from Texas. It is too old for radiocarbon assay, and there are presumably no deposits suitable for fission-track dating. Aronow (1993) considered it equivalent to the Montgomery and Bentley terraces of Louisiana, although a more recent stratigraphic chart for Louisiana lists the Lissie Alloformation as equivalent in time to the Bentley Alloformation (Lower Pleistocene), which is succeeded by the Montgomery Alloformation (Middle Pleistocene; Johnston *et al*. 2000). Autin (1993:10, Table 2) equates it with the Intermediate Complex, which in turn has been considered

Yarmouthian, pre-Sangamonian, or Sangamonian in age, generally Middle Pleistocene. Aronow (in Moore and Sanchez 1993:12) suggested the Lissie Formation is over 100,000 years old. Charles Winker considers it to be less than 1.4 million years old and at least 400,000 years old, and notes that reversed magnetic polarity measurements near Bellview suggest it is at least 700,000 years old (Winker 1991:103). Durbin, Blum, and Price (1997:Fig. 1) evidently equate the top of the Lissie Formation to the Matuyama-Brunhes polarity reversal at 780,000 BP. If this is the case, the extensive soil development and sesquioxide accumulations seen in the cutbank are not surprising. Horse (*Equus francisci*) remains have been reported from it (Lundelius and Stevens 1970).

Beaumont terrace surface

The Beaumont and Lissie formations are expressed mainly as coastwise terrace surfaces, but also extend up the valleys of major coastal rivers in the form of narrow flanking riverine terraces of equivalent age (Doering 1936:435 and Fig. 1). They are mapped as such by the *Geologic Atlas of Texas* for the Brazos and Colorado rivers, but not for the Guadalupe or San Antonio River, and only to a very limited extent for the Nueces River. Van Siclen (1991) divides the Beaumont coastwise terrace into Eunice (later) and Oberlin (earlier) terraces in the Houston area. There are no Beaumont terrace deposits in the immediate vicinity of Berger Bluff, nor does the Beeville-Bay City Sheet of *the Geologic Atlas of Texas* recognize any such deposits closer than Victoria, but Winker (personal communication, 1979) has identified several Coleto Creek terrace remnants of Beaumont age inset into older Lissie Formation deposits. The closest of these lie a little over a kilometer away, to the south-southeast and east-northeast (Figs. 4.3, 4.4). These Beaumont remnants rest at about 115 to 120 feet (35-37 m) in elevation, or

about 12 m above the contemporary creek (Table 4.3). This unit generally supports mesquite or post oak woodland similar to that on the Lissie terrace, except where it is cleared for cultivation. Denhawken-Elmendorf, Edna, Dacosta, and Straber soils are represented (Miller 1982:sheets 21 and 26). Blum and Price (1994:88) estimate a maximum age for the Beaumont Formation of about 600,000 years. There are thermoluminescence (TL) dates of 71,900±6100 and 91,700±7900 BP (Durbin, Blum, and Price 1997) and optically stimulated luminescence (OSL) dates ranging from 97,500±75,100 BP to 179,300±145,500 BP (Durbin 1999:Table 1) on Nueces River terrace deposits, and four dates ranging from 102,000±6000 BP to 119,000±9000 BP from Colorado River deposits (Blum and Price 1994:90) identified with the Beaumont Formation. Aronow lists radiocarbon dates of 34,610±1990, 39,600±????, and 43,600±1270 RCYBP uncal (Moore, Dureka, and Aronow 1996: 15). There are some faunal and floral assemblages (Aronow, Neck and McClure 1991; Elsik 1986) known from the Houston area.

Post-Beaumont surfaces

Berger Bluff itself consists of post-Beaumont sediments, and the rest of this chapter will be concerned with the nature of these sediments and their stratigraphic relationships, but the present discussion mostly concerns the mappable surfaces of these deposits.

Two distinct post-Beaumont terrace surfaces are tentatively recognized, *an upper surface (pBU)* associated with the stratigraphic section at the site, and a *lower surface*

(pBL). Winker does not distinguish these two surfaces.

The *upper post-Beaumont surface* rests at about 6 m (range, about 5-8 m) above the present bed of Coleto Creek. In the immediate vicinity of the site, the absolute elevation of this surface is about 98-102 feet MSL. At the site, the bluff edge lies about 8.0-8.5 meters above the water surface during base flow conditions. The upper post-Beaumont deposits are believed to date from the late Pleistocene to the late Holocene (Late Prehistoric in the archeological chronology). Dacosta series, Telferner series, Rupley fine sand, and Straber loamy fine sand occur on this surface.

The tentatively recognized *lower post-Beaumont surface* occurs at about 3.3 m above the contemporary creek channel. In the vicinity of Berger Bluff, it is represented by paired terrace surfaces at about 90 feet elevation (27 m) about a kilometer downstream where the creek makes an abrupt turn; these have not been examined in the field. Within the bounds of the Schroeder quad, the post-Beaumont surface slopes downstream at the rate of about 0.88 meters per kilometer, which is nearly the same as the Beaumont slope, 0.79 m/km, but significantly less than the modern channel gradient, 1.57 m/km. Both the upper and lower units are mostly represented by paired surfaces, but the lower surface includes some very narrow, linear surfaces that are usually (but not always) closer to the contemporary channel than the upper surface (Fig. 4.3). The upper surfaces seem to be somewhat more numerous and extensive than the lower surfaces; it is very unfortunate that none of the latter received any geomorphic inspection before the reservoir was constructed. No archeological sites in the Schroeder quad can be identified with the lower post-Beaumont unit. Most of these surfaces are below the pool level of the reservoir and are therefore unclassified by the Victoria County soil survey; the single exception on the

Schroeder quad is classified as Kuy loamy sand. All of the terraces that I have examined in this area appear to be fill terraces. Goelz (2003:page 3-1, Fig. 3-2) trenched and examined a terrace (less than two meters above the bed of Perdido Creek on the Fannin quad) that she interprets as an "erosional" (strath) terrace cut into Lissie and/or Goliad Formation sediments.

Well downstream from Berger Bluff, the cutbank shows a thick black clay loam A horizon over homogeneous brown sediments. In general the sediments exposed downstream from the site are much more homogeneous and have a much higher proportion of clay. During the Flume #3 project in 1983, two backhoe trenches were dug about 286 m downstream from Berger Bluff, at a site recorded as 41 GD 31 (shown on Fig. 1.30, south of the "GD 31" label; and Brown 1983:Fig. 2). The first trench (BHT 1) was located 16 m south of the lake shore and reached a maximum depth of 3.6 m below the terrace surface, which lies at 98.5 feet. No cultural material was found, and the deposits do not resemble the upper post-Beaumont deposits at Berger Bluff. Visual estimates of clay content (no lab data are available) are about 30% to 40% or more. In general, the sediment becomes less gray and more tan in color with depth, and the clay content in the samples collected appears to diminish with depth. A very tight, compact clay stratum was noted at 2.65 m. A soil coring device would not penetrate more than about 20 cm of the compact clay in the bottom of the trench. Caliche nodules (true accretional caliche nodules with botryoidal growth structure, not Goliad marl clasts) appear in the lowest three soil samples collected at 3.0 m and below, perhaps suggesting a fluctuating water table and seasonal drying. Snails were noted at about 3.0 m and below, probably all *Oligyra orbiculata tropica*.

These sediments are somewhat enigmatic. The surface here is nearly as high as at Berger Bluff, yet the deposits are lithologically distinct, indicating either that this is a remnant of the lower post-Beaumont surface, or else a separate and very distinct facies of the upper post-Beaumont unit. None of the sediments at a comparable elevation at Berger Bluff have such a high clay content.

The second backhoe trench (BHT 2) was located further to the south (56 m south of the lake shore) at the contact between the post-Beaumont and Lissie terraces; the sediments here are markedly different from those exposed in the first trench, but it is unclear whether they represent undisturbed Lissie deposits, or colluvium eroded off the Lissie scarp and mixed with post-Beaumont alluvium. Most of the section consists of very light-colored tan, clay-rich sediment. Below about 1.86 m, moderately abundant *Rabdotus* and *Oligyra* snails were noted, the clay is variegated with blue-gray streaks, and above this is a zone with small caliche nodules.

Beaumont (?) and post-Beaumont terraces on the Preiss property

On November 18, 1998, Cecil Calhoun and I briefly examined terrace deposits on the Preiss property in Goliad County. This area is west of Arnold Road, at the confluence of Twelvemile Coleto Creek and Fifteenmile Coleto Creek, above the head of the reservoir (Fig. 4.5; the area is also shown in the upper lefthand corner of Fig. 1.25). Lower areas had experienced flooding on three occasions shortly before our visit (October 6-7, October 18-20, and November 13-15, 1998). Located here (locality D-21) is an extensive surface lying about 25-30 feet (7.6-9.1 m) above the channel. The surface sediments are loose sand, and live oaks with trunk diameters up to 70 cm occur in groves

and motts (Fig. 4.17). These deposits actually enclose a small Goliad Formation outlier (capped with Willis Formation or other gravels) that stands on the south side of the creek where the road crosses. *The Geologic Atlas* classifies this surface as Pleistocene "fluviatile terraces undivided," while Winker (personal communication, 1979) classifies it as "Beaumont (?)."

Figure 4.17. Preiss Ranch, Diatom and Snail Sampling Locality D-21. Looking northwest; Cecil Calhoun is standing at sampling locality in live oak mott on Beaumont (?) terrace. Photo November 18, 1998.

Lying below this surface, at the confluence, is another surface about 10-20 feet (3-6 m) above the channel. At diatom sampling locality D-20A, the surface was measured

by hand level at about 3.75 m above water level. These deposits also consist of loose sand, supporting smaller motts with live oak trunks up to 30 cm in diameter (Fig. 4.18).

Figure 4.18. Preiss Ranch, Diatom and Snail Sampling Locality D-20, Area "A." Looking north-northwest across lower (?) post-Beaumont terrace. Coleto Creek is behind oak mott. Photo November 18, 1998.

The terrace scarp is mantled with loose, slumped fill, suggesting that the deposits are unconsolidated and perhaps relatively young. This surface is tentatively regarded as *lower post-Beaumont*, although without any subsurface view of the contact between the two deposits, it is impossible to be certain that these possible post-Beaumont sediments are really inset into older sediments. Because the area is located at the confluence of two major streams, it is possible that discharge from Twelvemile Coleto Creek has diverted

the flow from Fifteenmile Coleto Creek, causing it to cut an erosional bench into the higher surface. The surface showed clearly that the November 13-15 and October 18-20 floods (and possibly the preceding one as well) had overtopped the surface and flowed south to north here. A flood scour on the southwest edge of this terrace (Fig. 4.6) has a somewhat thin scatter of chert gravel up to 12-13 cm long (the largest clast was a small Goliad sandstone boulder 15 by 25 cm). This gravel did not appear to be a lag deposit, but rather Coleto Creek bedload material that had been rolled up onto the terrace surface by recent or older flooding, perhaps as a result of the kind of diversion suggested above, although other known examples of this kind of deposition usually involve larger, more coherent, flat-bottomed lobes of gravel deposited on fine-grained floodplains (Ritter 1975; Ritter and Blakley 1986). The original source is likely Willis Formation deposits somewhere upstream.

A grain-size histogram for a sediment sample collected at 2-4 cm below the surface at locality D-20A is shown in Figure 4.7. With a prominent sand mode at 1.5 to 2.0 ϕ, this sample is somewhat coarser than all the Berger Bluff samples (only the colluvial rill deposits in N109 E96 are coarser), and resembles a Coleto Creek bedload sample (Figure 1.48, top) more closely than anything else. This is consistent with the idea that this might be a very recent (Late Prehistoric or protohistoric?) terrace, formed during a recent climatic period as a result of very flashy flooding. No archeological material was seen anywhere on these terraces in our brief visit.

Meander scars of unknown age

North of Berger Bluff, on the opposite side of the creek, lies a pair of linked, poorly defined arcuate meander scarps of very large radius (Fig. 4.4, "1," "2"). These are of unknown age, but truncate the Beaumont-age surface slightly (they are indistinct topographically and in airphotos). These have estimated radii of curvature of about 285 and 623 m, respectively (the former is elliptical rather than circular). The soil units (Kuy loamy sand, Rupley fine sand, and Straber loamy fine sand) mapped in the vicinity do not correspond to the spatial limits of the meander scars, and the degree of typical soil development gives no clues to the age of the scars.

East and north of the site are two much smaller meander loops (Fig. 4.4, "3," "4") with estimated radii of roughly 250 and 313 m, respectively. They are separated but probably contemporaneous, and are inset into the floor of the larger pair of scars. One truncates upper post-Beaumont terrace fill, while the other encircles what is tentatively interpreted as an isolated remnant of upper post-Beaumont fill. These meander loops are clearly much younger than the first pair. Drainage in both is clockwise. The first of these smaller loops has three prehistoric archeological sites (41 VT 49, 50, 51) in the interior part of the loop, but there are no diagnostic artifacts, and shovel tests reached a maximum depth of only about 80 cm. Sediments are reported as sandy loam or sand, with gray clay at a depth of 60 cm at 41 VT 50 (Fox and Hester 1976:42-43).

Loops "3" and "4" are incised below a bank elevation that appears to be about 7.6-9.1 m above the contemporary creek channel, or in other words, at or slightly above the upper post-Beaumont surface. They are remnants of a tightly meandering channel

pattern that differs greatly from the current straight pattern. A fifth meander alcove downstream from the site ("5" in Fig. 4.4) is infilled with sediments tentatively associated with the lower post-Beaumont surface; the radius of curvature for this scarp is estimated at about 145 m.

Remarks

Very large, arcuate meander scarps and coarse-grained terrace deposits of Deweyville age have been identified in most of the major river valleys of the coastal plain. Typically, two to three different terraces occur in the complex, with steeper gradients than modern floodplains (Blum, Morton, and Durbin 1995:54). Radiocarbon assays of 13,230±110 RCYBP (Baskin 1991:998), 13,250±250, 19,900±500, and 25,700±800 RCYBP uncal (Pearson, Davis, and Tamers 1966:458) and thermoluminescence) assays ranging from 31,400±2200 BP to 52,600±5300 BP (Durbin, Blum, and Price 1997) have been obtained. Optically stimulated luminescence dates of 26,000±16,800 to 32,100±4100 BP have been obtained from Nueces River terraces (Durbin 1999:Table 1). Blum, Morton and Durbin suggest that these oversized meanders represent a Pleistocene climatic regime featuring greater annual runoff than at present, but in the form of floods of only moderate magnitude. Deweyville gravels in southeast Louisiana are finer-grained and better sorted than both Prairie (Beaumont) formation and Holocene gravel deposits (Self 1983:Fig. 5), supporting the notion that glacial to late-glacial discharge rates were higher than at present, but much less flashy. The lower Guadalupe River valley has evidence of either two (Weinstein 1992:Fig.2.7; and *Geologic Atlas of Texas*, Beeville-Bay City Sheet) or three (Blum, Morton, and Durbin 1995:54) of these terraces, including some in the Coleto Creek valley near its confluence

with the Guadalupe River.

There are no comparable coarse-grained deposits known in the vicinity of Berger Bluff. The only features that might plausibly compare to the known Deweyville features at the mouth of Coleto Creek are the large meander scarps, loops "1" and "2" of Figure 4.4, and nothing is known about the sediments with which they appear to be partially backfilled.

In summary, the immediate geologic context of Berger Bluff is clearly a patchwork of surfaces and sedimentary units of greatly differing antiquity and degrees of preservation and weathering. It is very unfortunate that the original reservoir survey was done in 1975 before geoarcheological assessments of fluvial environments became a routine part of CRM work. As a result, except for the site itself and the immediate area around it, most of the proposed terrain units that I have presented here have not been ground truthed. Because of reservoir flooding, they are now inaccessible. My classification of upper and lower post-Beaumont surfaces should be regarded as tentative. Localities 3 and 5 in Figure 4.4 particularly invite geoarcheological assessment.

STRATIGRAPHY OF THE POST-BEAUMONT DEPOSITS AT BERGER BLUFF

Overview

The basic stratigraphic framework for the post-Beaumont deposits was defined by Glen Evans, who visited the site during the summer of 1979, while the large excavation block in the upper deposits was being dug. Evans recognized five major strata, numbered 1-5 from the base of the bluff upward (Figs. 4.19, 4.20). That classification was adopted both for the report on the upper deposits (Brown 1983) and for the present study. However, I have formally subdivided stratum 2 (as units 2A through 2E) and have informally subdivided stratum 4 (as units 4A through 4E).

Strata 1, 2, and perhaps 3 comprise the indurated "bench" deposits (Pleistocene and Holocene) and are of direct concern here, while strata 4 and 5 comprise the "upper" deposits (Holocene) and will be discussed in much less detail. In several respects, stratum 3 is transitional between the bench and upper deposits and some justification could be found for putting it in either category, but I have chosen to include it as part of the bench deposits. There is no obvious stratigraphic marker that divides the Pleistocene from the Holocene at Berger Bluff – rather, there are evolutionary and time-lagged changes in the regional environment.

The environmental history and stratigraphy of the site are so intertwined that it is difficult to speak of one without some understanding of the other. Perhaps the simplest way to introduce the subject is to give a very brief capsule history of events, a history that will be filled out in much more detail as we work our way through the geology and biology of the site.

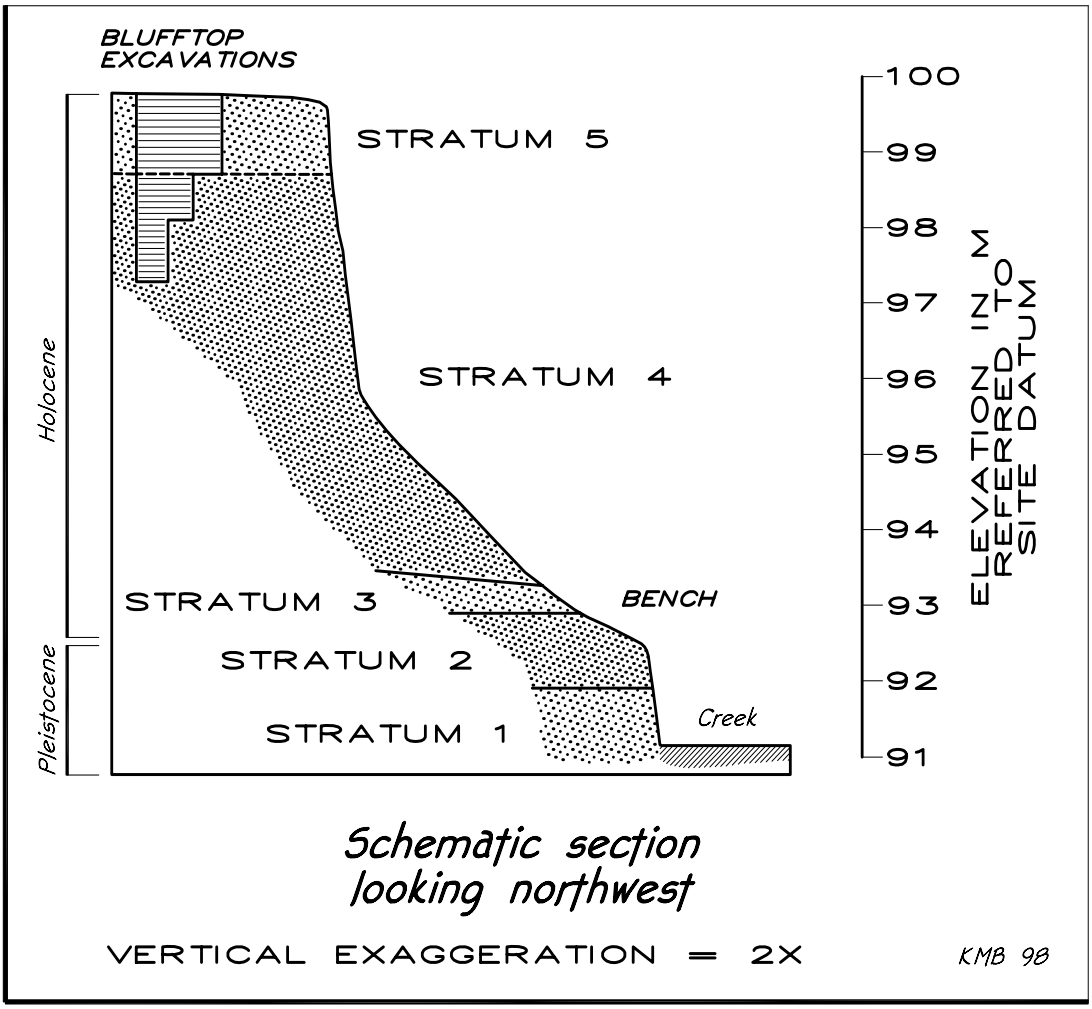


Figure 4.19. Schematic View of Stratigraphy at Berger Bluff. View looking upstream (northwest), showing the major stratigraphic units (subdivisions not indicated). Vertical exaggeration is 2X.

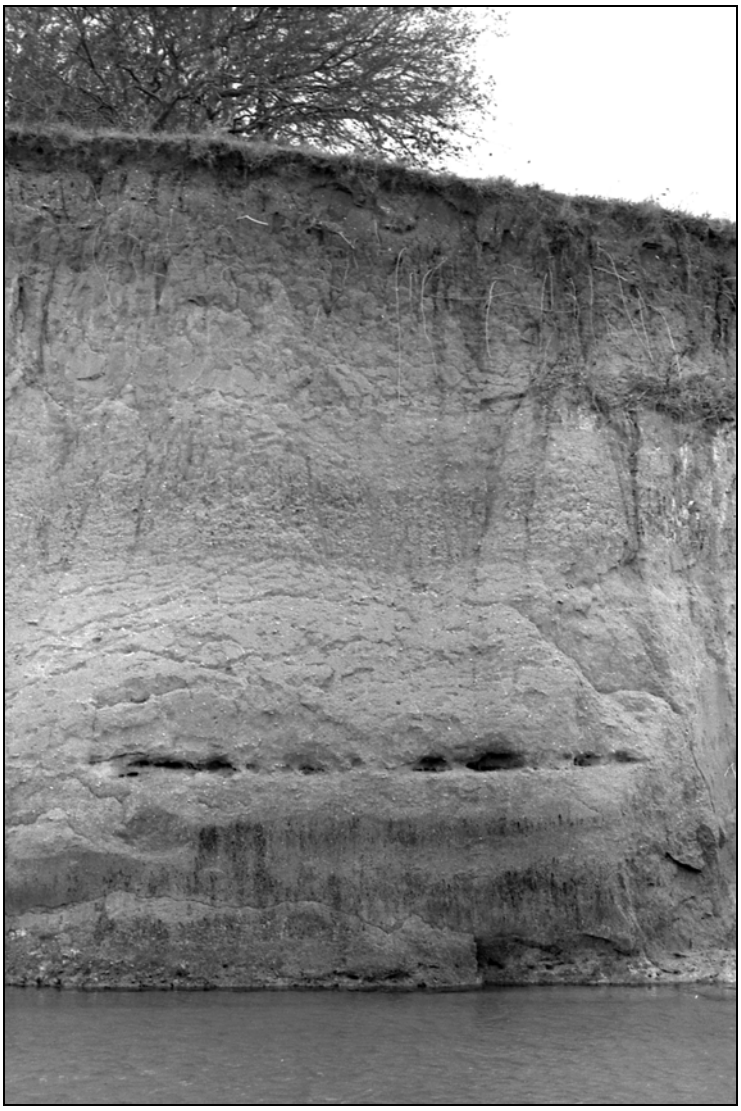


Figure 4.20. Photographic Section of Berger Bluff. Looking southwest at complete section of Berger Bluff. Excavated area is out of view to left, ravine is out of view to right. Prominent voids are areas where gravel pockets (probably representing the entry of hurricanes into the drainage in the early Holocene) have washed out. Dark zones below the pockets are damp zones (with mold growth) produced by capillary wetting from the creek. Wavy structures above the pockets are a thin veneer of sheetwashed sediment, not primary sedimentary structures. Note modern soil development on slowly eroding surface at top of profile. Photo November 8, 1979

Compared to the later Holocene and the present, regional temperatures were cooler, during the Younger Dryas and earliest Holocene (despite that fact that insolation was peaking, in large part because of the continued meltwater feed to the Gulf), evaporation rates were lower, winter rainfall was probably greater than in the Holocene, turbulent weather events such as hurricanes or fast-moving spring and fall Arctic fronts were nonexistent, stream discharge was muddier but flashy discharge events were rare or nonexistent, ground cover was much more extensive, sheet erosion was greatly retarded, sediment supply to the creek was much finer-grained, the creek valley was wider and flatter, the floodplain tree canopy was more extensive, and the creek was not nearly as deeply incised. These factors combined to produce two important results: 1) groundwater recharge rates were probably much higher in the catchment than at present, and groundwater movement through the Evangeline Aquifer was much greater; 2) the floodplain was experiencing slow aggradation instead of the relatively rapid incision and net removal of sediment from the catchment that occurred until the reservoir was completed in 1980. In terms of Nanson and Croke's (1992) genetic classification of floodplains, the Coleto Creek floodplain probably resembled class C1 (laterally stable single-channel floodplains) in their Class C (low-energy cohesive floodplains).

Fine-grained, rather muddy sand accumulated on the flat, floodplain surface and was partially cemented by calcium carbonate, a phreatic carbonate deposited by groundwater flowing out of Goliad sandstone bedrock. In some levels, phreatic carbonate makes up over 25% of the dry weight of the sediment. Carbonate deposition either kept pace with aggradation or, more likely, filled pores in the matrix later as additional sediment accumulated above.

No actual buried spring conduit has been located at Berger Bluff, but it seems apparent that there were one or more springs or seeps at the base of the valley wall, probably located not far to the south of the excavated area, closer than the contemporary spring (Fig. 1.31) situated in the ravine to the west. There may have been other small ravines or gullies, now buried but formerly cutting into the sandstone bedrock and providing an outlet for groundwater seepage. Spring sites in the eastern US are often associated with peat deposits, and sites in the western US with organic "black mats." but no such deposits are present at Berger Bluff. Muddy units rich in silt and clay alternated with cleaner sandy units as the bench aggraded. The silt and clay are evidence of the sustained flooding necessary to allow fine sediments to drop out of the water column, and the clay makes the sediment especially resistant to erosion.

At some point during the early Holocene, annual precipitation declined, and as a result, aquifer recharge and discharge rates also declined greatly. After this point, sediments continued to accumulate on the floodplain, but saturation with phreatic carbonate was greatly diminished, so that newly added sediments lacked the binding cement found in the earlier deposits. There are carbonate filaments and nodules in the upper deposits, but it is pedogenic carbonate and is not extensive enough to act as a cement.

Concurrently with this change, the nature of the sediments aggrading on the floodplain began to change. Overall, disregarding strata, the bench sediments are about 36% sand, 31% silt, and 32% clay, an equable mix that makes for fairly cohesive sediments even without the carbonate binder. The uppermost bench unit, stratum 3, is a thick, silty stratum that perhaps visually resembles a redeposited soil. Strata 4 and 5

apparently accumulated not much more rapidly during the balance of the Holocene, but are texturally different: the proportions of silt and gravel stay roughly the same, but clay drops to less than 13%, while sand increases to over 51% of the sediments, greatly boosting the friability of these upper deposits. The change in sediment texture is probably due to reduction in ground cover in the drainage basin upstream (due to regional aridification) and increasingly seasonal precipitation as the jetstream followed the retreating Laurentide ice sheet northward. Flashier discharge removed the periods of standing water that had previously contributed sedimentary fines, and also began to strew occasional lenses of gravel across the floodplain whenever more violent floods occurred. The floodplain may have evolved into some type of Class A (high–energy non-cohesive) floodplain in the genetic classification of Nanson and Croke (1992).

As a result of the dramatic increase in sediment friability in or above stratum 3, the bluff face has retreated above stratum 2E, leaving a prominent, indurated erosional bench. The division into "bench" and "upper" sediments, then, has true paleoenvironmental significance and is not simply a minor geomorphological feature. The localization of this retreat to a relatively small alcove 22 m long suggests that of the two factors, the reduction in cement is at least as important for friability as the change in texture. To the west of the bench, in an area perhaps not reached by groundwater seepage, the bluff has eroded uniformly into a single vertical face (Figs. 1.29, 4.20).

The top of the bench, then, is not only a visible geomorphic feature, but a paleoenvironmental benchmark. If it had occurred neatly at the Pleistocene-Holocene boundary, the division into "bench" and "upper" sediments would mark the beginning of the Holocene. However, the most important environmental shift appears to be lagged well

into the early Holocene, perhaps by a millennium and a half, and the evidence for and causes of this lag will be discussed at length in the pages to come. Fine sandy sediments continued to accumulate at a fairly rapid rate, with no evidence of erosion, until some time in the late Holocene, at which point Coleto Creek began to incise rapidly downward, cutting to the base level it occupied in 1979, and exposing about nine meters of sedimentary history.

In the sections to follow, I will provide descriptive summaries of all the strata, working upward from stratum 1, and then discuss some topics that embrace all the strata – texture, magnetic susceptibility, carbonate content, micromorphology, and inclusions. Most of these properties are expressions of processes that crosscut strata, so most of the analysis will focus on vertical plots, rather than stratum-by-stratum analysis. Counts and weights of materials found in the excavations often vary more from unit to unit than they do from stratum to stratum, so it is difficult to characterize the strata by calculating averages of recovered items. One of the most conspicuous and interesting features of the bench deposits is the regular alternation of muddy and sandy units, perhaps forming pairs or couplets. A major goal of analysis is to identify the source of this cyclic bedding, and the final sections will present and evaluate some competing hypotheses (buried soils, autocyclic bedding, graded bedding, and allocyclic bedding). Discussion of the age of the deposits will be deferred to the chapter on radiocarbon dating.

The reader should also understand that there are two kinds of gravel deposits buried in the bench deposits. Along the cutbank, and exposed in a few of the excavation units near the cutbank, lenses, pockets and stringers of chert and quartz pea gravel can be seen, often supported in a matrix of coarse sand. Little or no calcareous material is present This material is similar (both in size grading and lithology) to the gravel that

could be seen in the submerged bed of the creek in 1979, and it represents material brought down the creek from the various Miocene and Quaternary geologic units exposed in the drainage basin upstream. It has some significance for interpreting the hydrologic history of the creek.

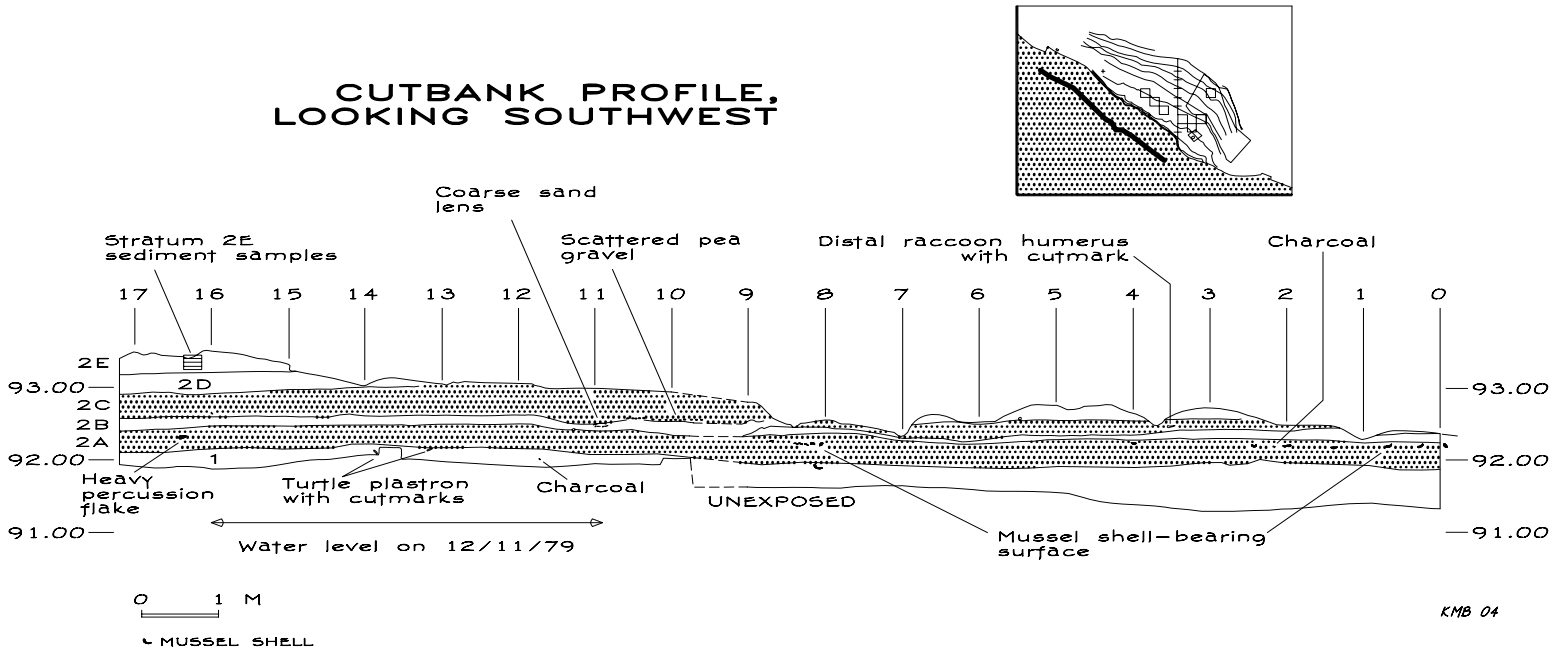
The second kind of gravel consists of small lenses of highly calcareous gravel and sand exposed in unit N109 E96, about six meters southwest of the cutbank. The material is highly variable in composition and consists of carbonate nodules, pebbles and sand, or carbonate-cemented aggregates of calcareous, quartz, or chert sand, along with a smaller proportion of chert or quartz gravel, supported in a matrix of quartz sand. The carbonate clasts are generally less well rounded than the chert or quartz clasts and have not been transported as far; in the three samples analyzed for lithology, they constitute about 29-93% of the coarsest grades. The maximum caliber of the carbonate nodules is larger (over 3 cm in maximum axis length) than the chert or quartz, but the density (weight per spherical volume of the clast) is considerably less. This material has been eroded from Goliad Formation bedrock that was exposed somewhere along the valley wall to the south or southwest, moved a short distance toward the creek axis, and redeposited on the slowly aggrading floodplain as small fan or outwash deposits. It probably has no particular climatic significance.

Figures 4.19-4.23 and 4.53 illustrate the bench stratigraphy with photos and profiles of the cutbank. Figures 4.24-4.52 are taken from the individual excavation units and provide more detailed profiles, plans, and a few photos, accompanied by stratigraphic plots of inclusions and magnetic susceptibility data. Appendix 4, which lists counts and

weights of items recovered from the 1/4-inch screen, also lists stratum assignments for each excavated level.

Figure 4.21. Bench Cutbank, Looking West. This view (January 26, 1980) looking upstream was taken after a flood had washed the face clean. Dark zone just above base of profile is stratum 2A. Excavations are out of view to right. Scale is 50 cm long.

Figure 4.22 *(following page)*. Cutbank Profile. This seventeen-meter profile was drawn along the slightly irregular northwest-southeast trending cutbank, extending from near the E100 grid line downstream past the stratum 2E sampling locality (see inset). Upstream is to the right in the view shown here. The arbitrary meter marks shown do not correspond to the grid system. Slumped material covers the base of the profile down to the waterline.


CUTBANK PROFILE,
LOOKING SOUTHWEST
Coarse sand lens
Stratum 2E sediment samples
Scattered pea gravel
Distal raccoon humerus with cutmark
Charcoal
17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
2E
2D
2C
2B
2A
93.00
92.00
91.00
Heavy percussion flake
Turtle plastron with cutmarks
Charcoal
UNEXPOSED
Mussel shell-bearing surface
Water level on 12/11/79
0 1 M
MUSSEL SHELL
KMB 04

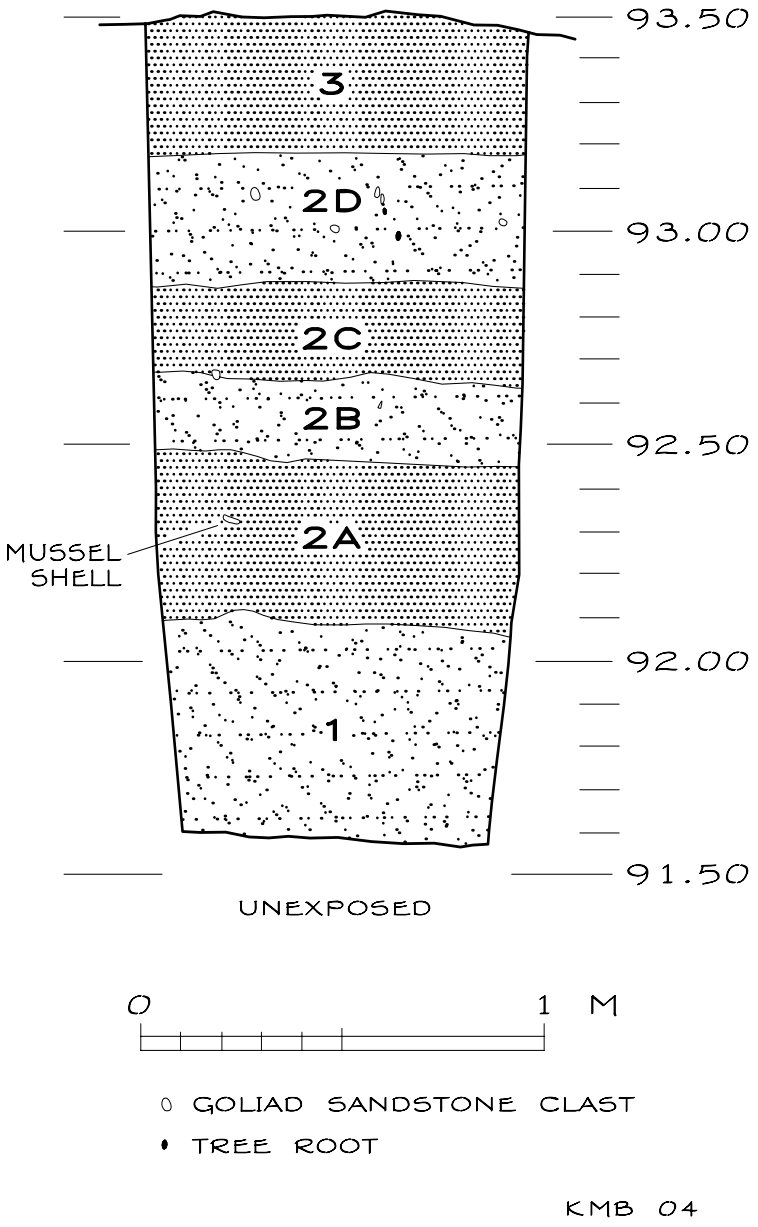


Figure 4.23. West Cutbank Profile. Looking south-southwest at profile recorded for a narrow, cleaned section of the cutbank near the western (upstream) end of the bench area. The upper surface is defined by a narrow ledge where the eroded bench surface merges with the vertical bluff face upstream. Perhaps better than any other, this profile illustrates the alternating rhythm of muddy and sandy units.

Figure 4.24 *(following page)*. Profile of Unit N109 E103. This is a continuous, unfolded profile of all four walls of this 1 x 1 m excavation unit. Elevation in meters is shown on the left. The top boundary is the eroded surface of the bench.

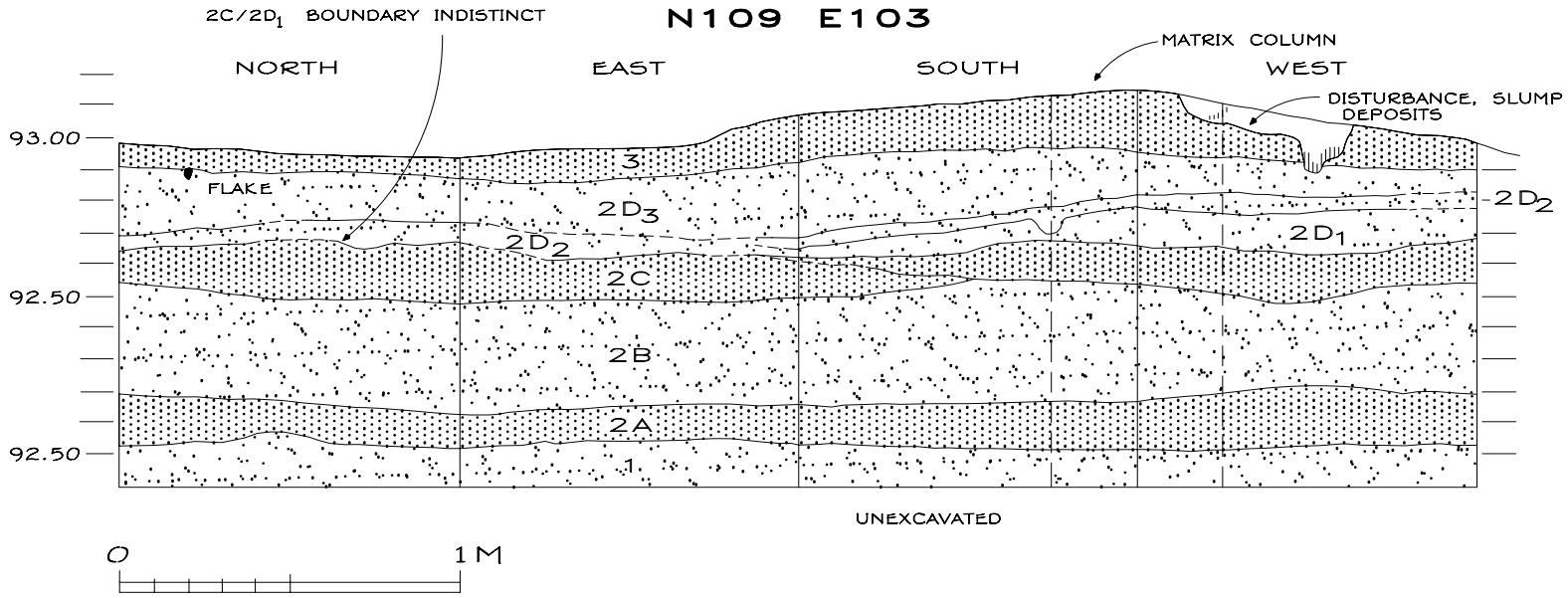

2C/2D1 BOUNDARY INDISTINCT
N109 E103
MATRIX COLUMN
NORTH
EAST
SOUTH
WEST
DISTURBANCE, SLUMP DEPOSITS
93.00
92.50
92.50
FLAKE
3
2D3
2D2
2C
2B
2A
1
2D2
2D1
UNEXCAVATED
0
1 M
KMB 04

Figure 4.25 *(following page)*. N109 E103, Stratigraphic Plots of Screened and Magnetic Susceptibility Samples. The top two panels show vertical double-axis plots of clasts (left, chert gravel, Goliad sandstone clasts, caliche nodules) and diagenetic constituents (right, calcareous rhizoconcretions and ferromanganese nodules) expressed as densities (counts or weights per cubic meter). The bottom two panels show magnetic susceptibility data. Low and high-frequency data are in chi units. The coefficient of frequency dependency is a unitless ratio. Note that in this and the following plots, the uppermost samples may differ somewhat in elevation for the screen samples compared to the susceptibility samples. Note that shading is only an approximate indication of the vertical position of muddy units.

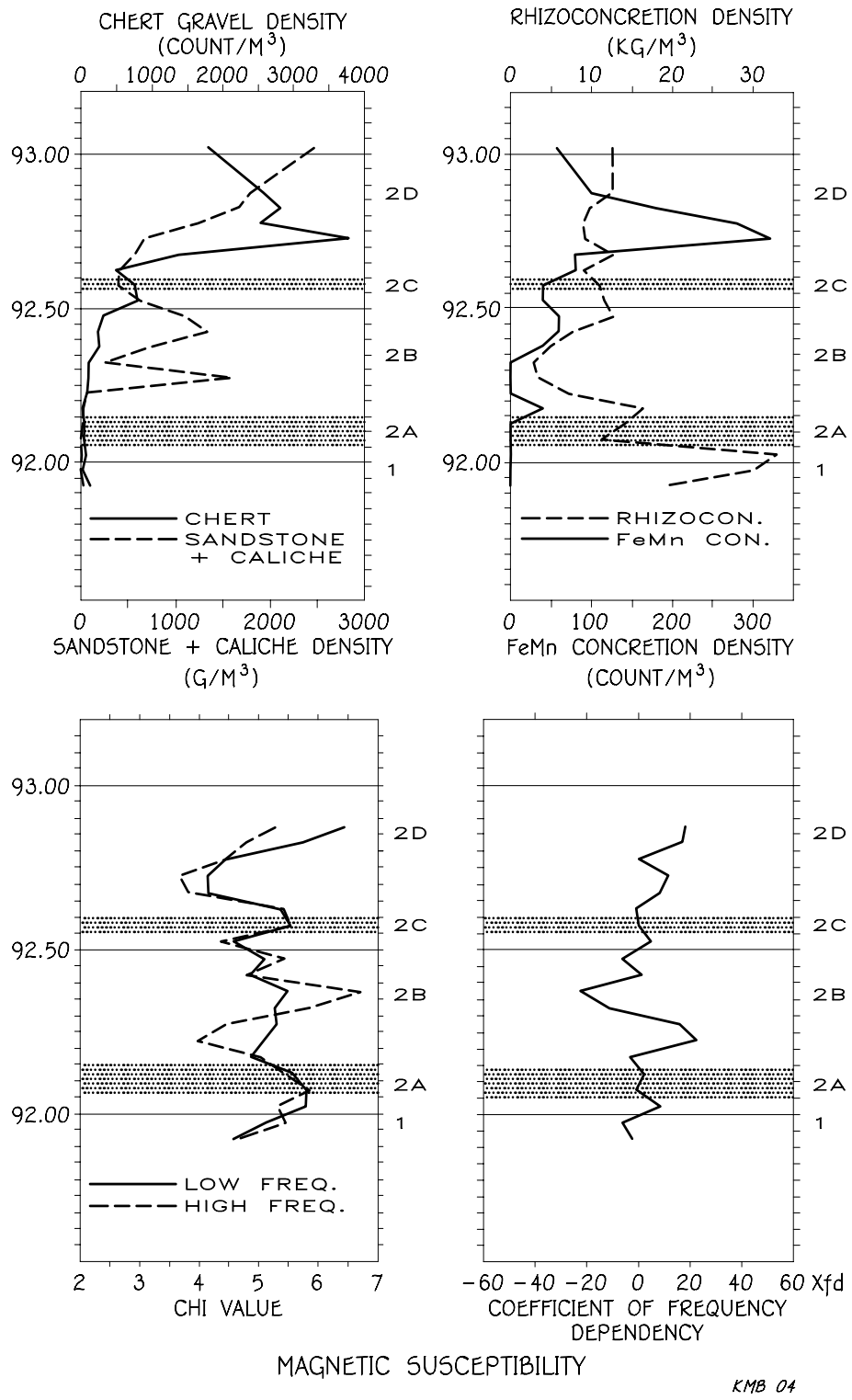

N109 E103
CHERT GRAVEL DENSITY
(COUNT/M3)
0 1000 2000 3000 4000
93.00
92.50
92.00
2D
2C
2B
2A
1
CHERT
SANDSTONE
+ CALICHE
0 1000 2000 3000
SANDSTONE + CALICHE DENSITY
(G/M3)
RHIZOCONCRETION DENSITY
(KG/M3)
0 10 20 30
RHIZOCON.
FeMn CON.
0 100 200 300
FeMn CONCRETION DENSITY
(COUNT/M3)
LOW FREQ.
HIGH FREQ.
2 3 4 5 6 7
CHI VALUE
-60 -40 -20 0 20 40 60 Xfd
COEFFICIENT OF FREQUENCY
DEPENDENCY
MAGNETIC SUSCEPTIBILITY
KMB 04

Figure 4.26 *(following page)*. Profile of Unit N110 E102. This is a continuous, unfolded profile of all four walls of this 1 x 1 m excavation unit. Elevation in meters is shown on the left. The top boundary is the eroded surface of the bench. Feature 6 was encountered in the northwest corner, so it appears at both ends of the unfolded profile. The thin unlabeled stringer just above Feature 6 on the left side, enclosed in stratum 2A, is a thin zone with calcareous concretions.

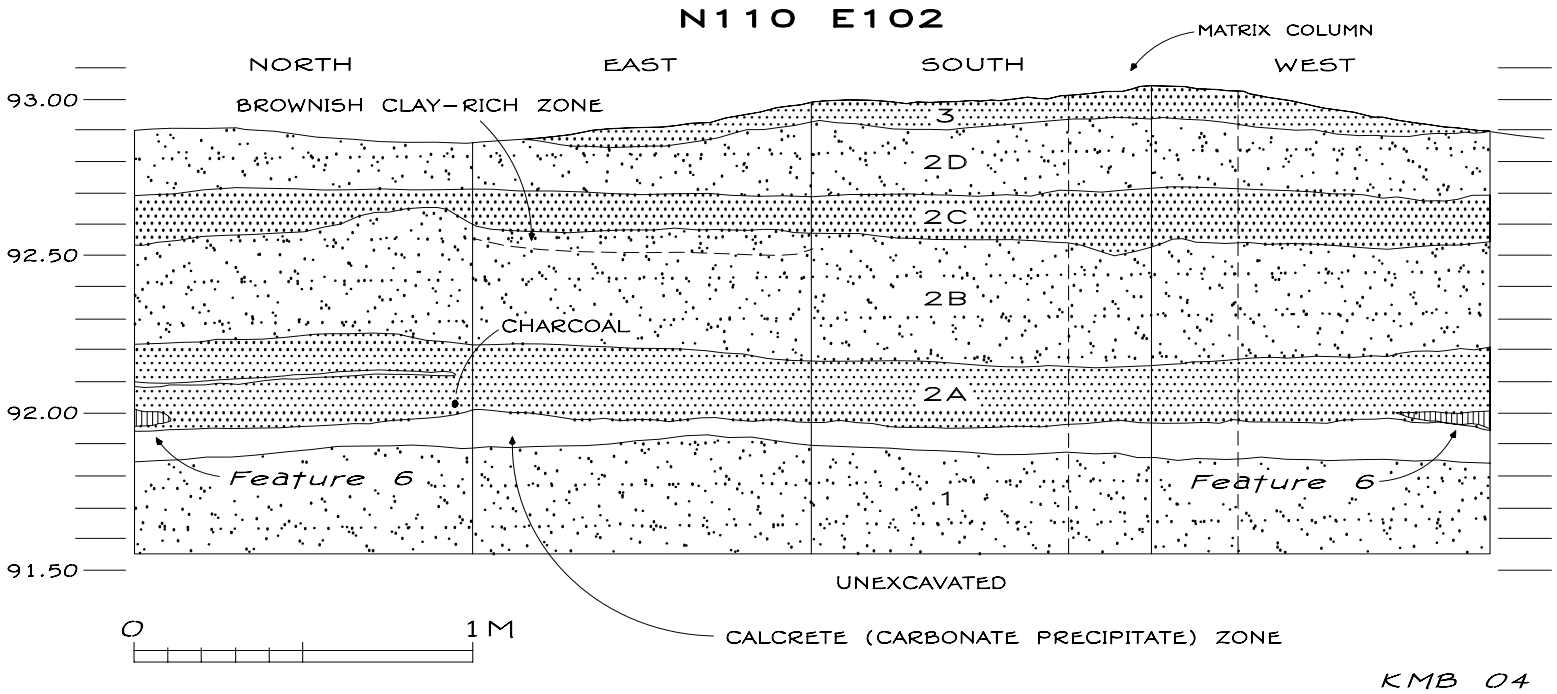
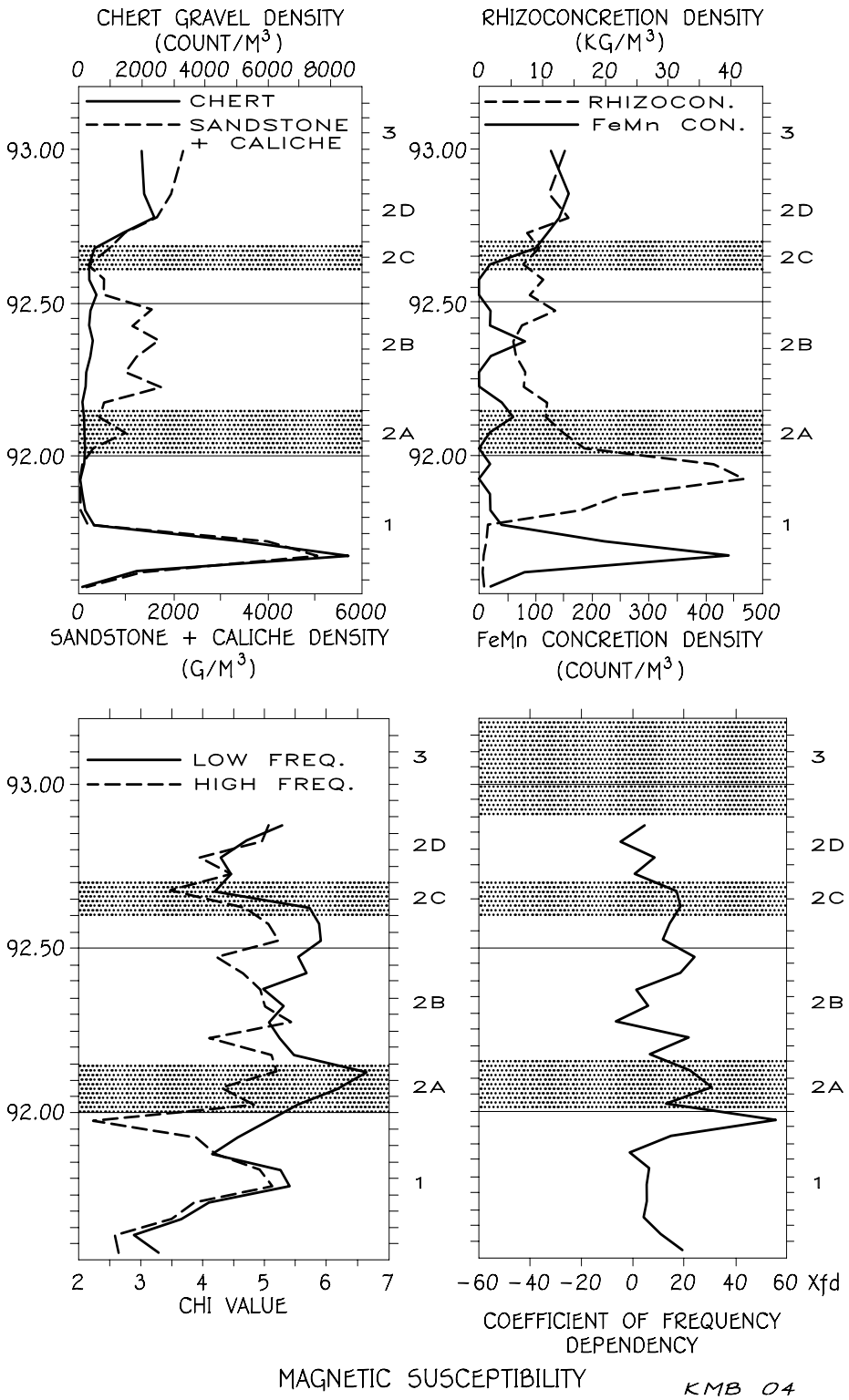

N110 E102
MATRIX COLUMN
NORTH
EAST
SOUTH
WEST
93.00
92.50
92.00
91.50
BROWNISH CLAY-RICH ZONE
3
2D
2C
2B
2A
1
CHARCOAL
Feature 6
Feature 6
UNEXCAVATED
CALCRETE (CARBONATE PRECIPITATE) ZONE
0
1 M
KMB 04

Figure 4.27 *(following page)*. N110 E102, Stratigraphic Plots of Screened and Magnetic Susceptibility Samples. The top two panels show vertical double-axis plots of clasts (left, chert gravel, Goliad sandstone clasts, caliche nodules) and diagenetic constituents (right, calcareous rhizoconcretions and ferromanganese nodules) expressed as densities (counts or weights per cubic meter). The bottom two panels show magnetic susceptibility data. Low and high-frequency data are in chi units. The coefficient of frequency dependency is a unitless ratio. Note that shading is only an approximate indication of the vertical position of muddy units.


N110 E102
CHERT GRAVEL DENSITY
(COUNT/M3)
0 2000 4000 6000 8000
CHERT
SANDSTONE + CALICHE
93.00
92.50
92.00
3
2D
2C
2B
2A
1
0 2000 4000 6000
SANDSTONE + CALICHE DENSITY
(G/M3)
RHIZOCONCRETION DENSITY
(KG/M3)
0 10 20 30 40
RHIZOCON.
FeMn CON.
0 100 200 300 400 500
FeMn CONCRETION DENSITY
(COUNT/M3)
LOW FREQ.
HIGH FREQ.
2 3 4 5 6 7
CHI VALUE
-60 -40 -20 0 20 40 60 Xfd
COEFFICIENT OF FREQUENCY
DEPENDENCY
MAGNETIC SUSCEPTIBILITY
KMB 04

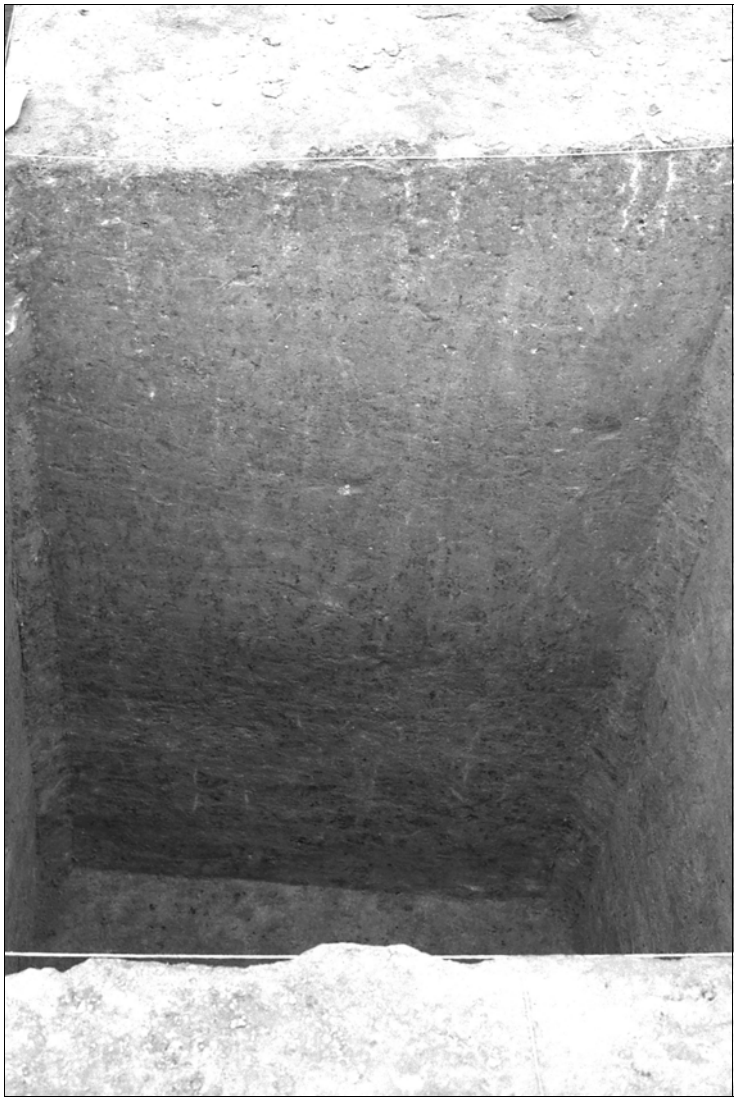


Figure 4.28. N110 E102, South Wall. Looking down and south at profile wall, no scale. Wavy crosslaminations marked by cream-colored carbonate stains can be seen in the lower third of the profile, but the calcrete zone at the base of stratum 2A is not apparent in this photo. Photo December 17, 1979.

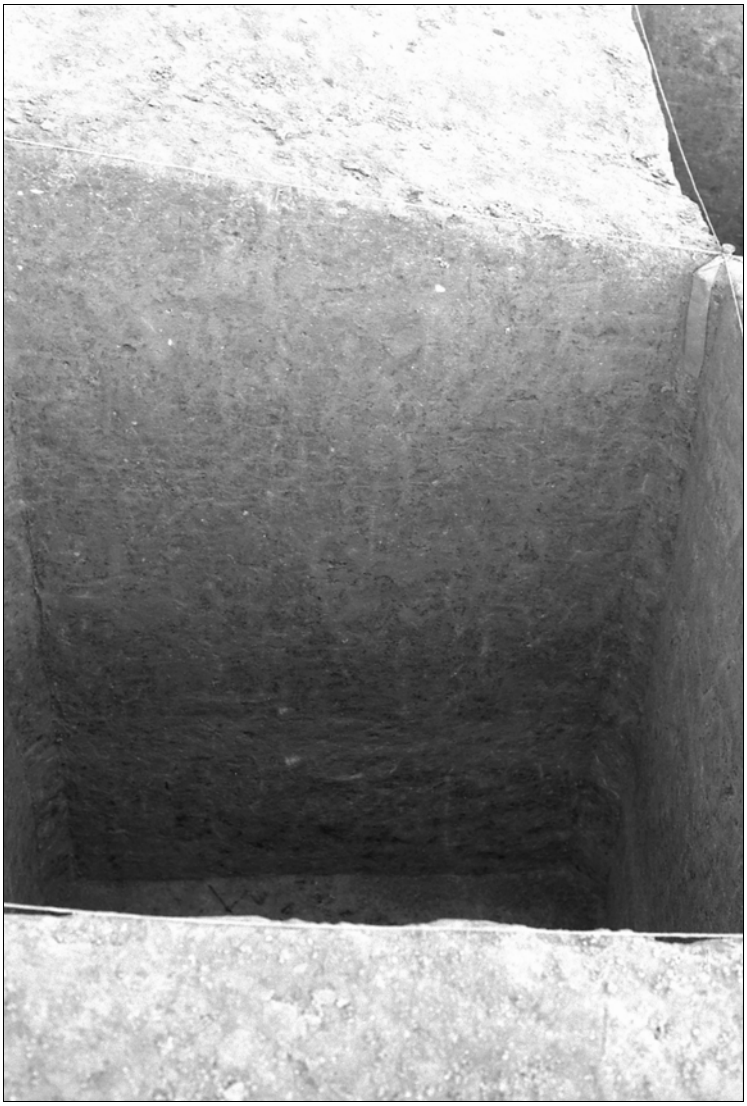
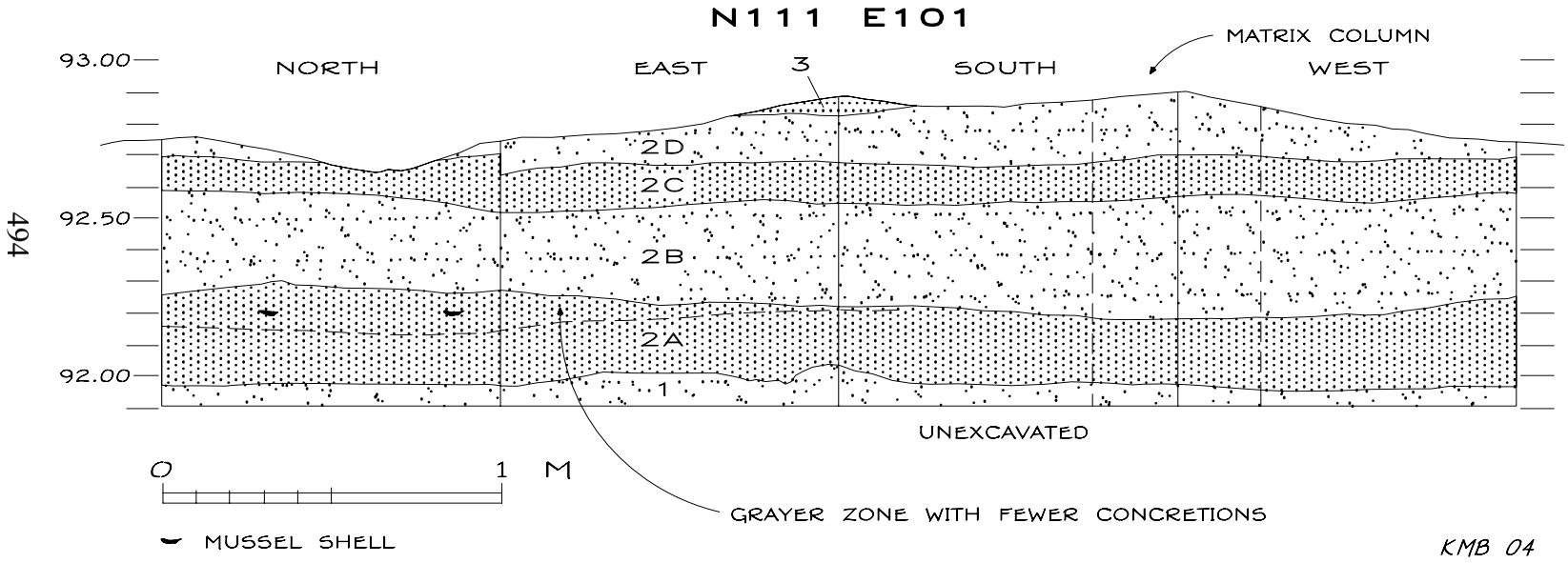


Figure 4.29. N110 E102, West Wall. Looking down and west at profile wall, no scale. Wavy crosslaminations marked by cream-colored carbonate stains can be seen in the lower third of the. Feature 6 appears in the righthand corner of the unit, but is also not readily visible in this photo. Part of unit N111 E101 can be seen in the upper right corner. The dark zone below the midpoint of the profile is stratum 2A, but the calcrete zone at the base of stratum 2A is not apparent in this photo. Photo December 17, 1979.

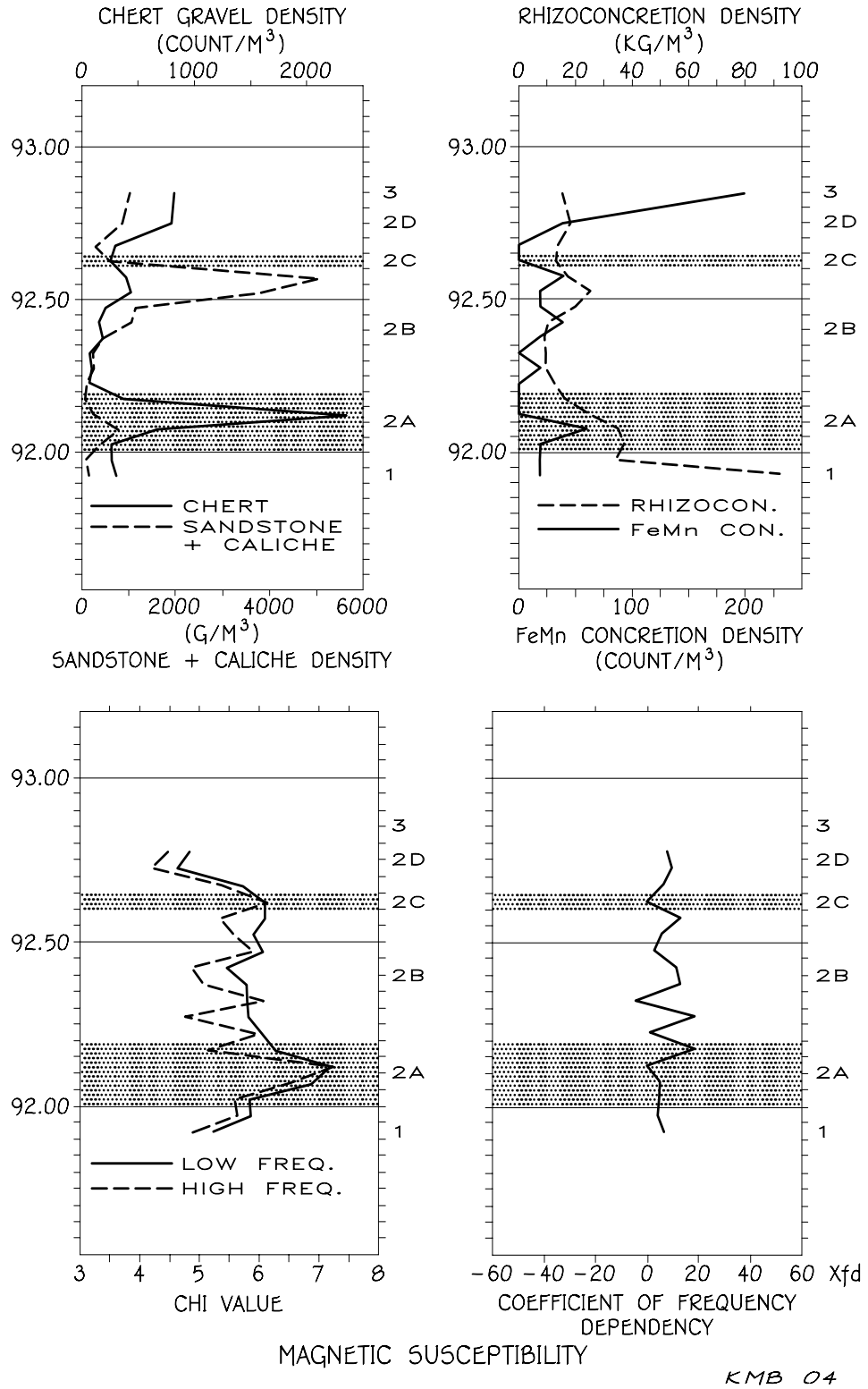
Figure 4.30 *(following page)*. Profile of Unit N111 E101. This is a continuous, unfolded profile of all four walls of this 1 x 1 m excavation unit. Elevation in meters is shown on the left. The top boundary is the eroded surface of the bench. In two of the walls, the upper part of stratum 2A is distinguished by a grayer color, fewer concretions, and some freshwater mussel shells.


N111 E101
MATRIX COLUMN
93.00
NORTH
EAST
3
SOUTH
WEST
2D
2C
92.50
2B
2A
92.00
1
UNEXCAVATED
0
1 M
GRAYER ZONE WITH FEWER CONCRETIONS
MUSSEL SHELL
KMB 04

494

Figure 4.31 *(following page)*. N111 E101, Stratigraphic Plots of Screened and Magnetic Susceptibility Samples. The top two panels show vertical double-axis plots of clasts (left, chert gravel, Goliad sandstone clasts, caliche nodules) and diagenetic constituents (right, calcareous rhizoconcretions and ferromanganese nodules) expressed as densities (counts or weights per cubic meter). The bottom two panels show magnetic susceptibility data. Low and high-frequency data are in chi units (note scale differs somewhat from similar plots for other units). The coefficient of frequency dependency is a unitless ratio. Note that shading is only an approximate indication of the vertical position of muddy units.

N111 E101



MAGNETIC SUSCEPTIBILITY

KMB 04

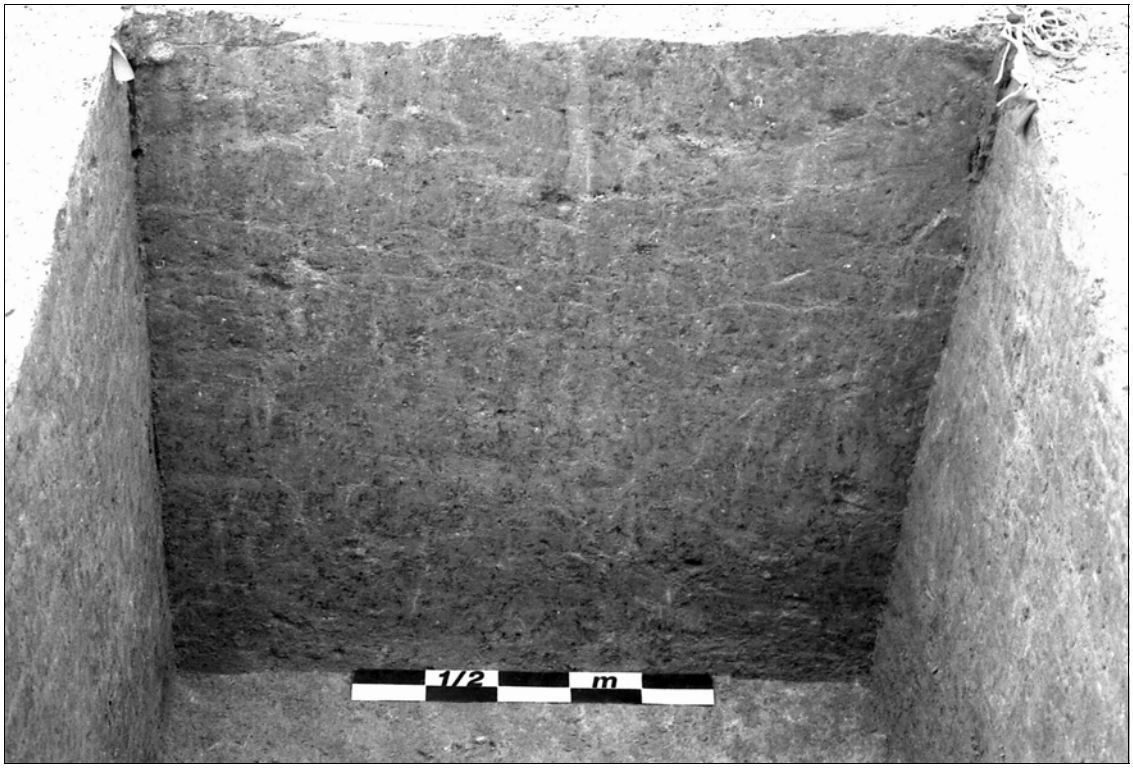


Figure 4.32. N111 E101, South Wall. Looking down and south at profile wall; scale is 50 cm long. Note occasional vertical burrows or root molds, widely scattered wavy crosslaminations. Photo December 21, 1979.

Figure 4.33. N111 E101, West Wall. Looking down and west at profile wall; scale is 50 cm long. Edge of mussel shell protrudes from stratum 2A at right. Photo December 21, 1979.

Figure 4.34 *(following page)*. Profile of Unit N112 E99. This is a continuous, unfolded profile of all four walls of this 1 x 1 m excavation unit. Elevation in meters is shown on the left. The top boundary is the eroded surface of the bench. Note occasional Goliad sandstone clasts, and mussel shells appearing in both muddy units (2A and 2C). The origin of the large disturbance in the northeast corner is unknown.

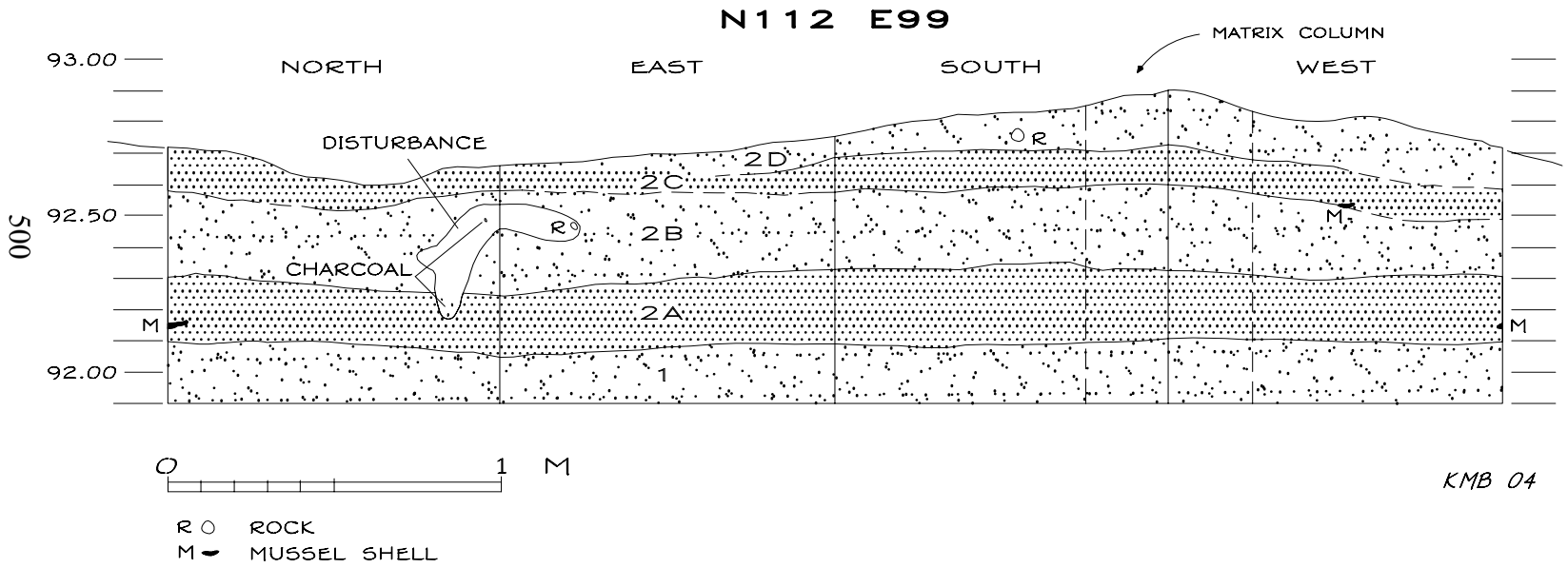
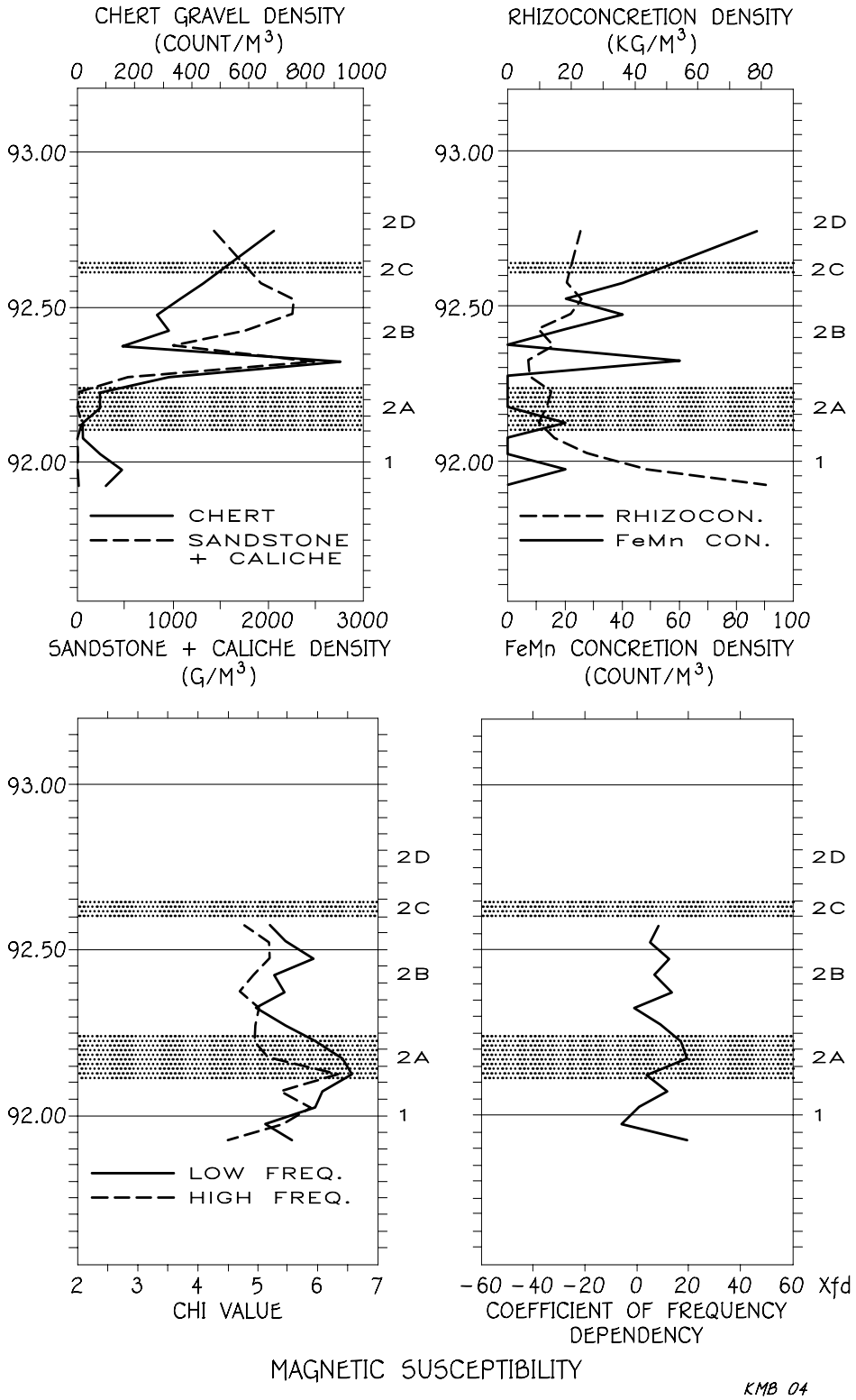

N112 E99
MATRIX COLUMN
93.00
NORTH
EAST
SOUTH
WEST
DISTURBANCE
R
2D
2C
2B
2A
1
CHARCOAL
M
92.50
92.00
500
0
1 M
KMB 04
R ROCK
M MUSSEL SHELL

Figure 4.35 *(following page)*. N112 E99, Stratigraphic Plots of Screened and Magnetic Susceptibility Samples. The top two panels show vertical double-axis plots of clasts (left, chert gravel, Goliad sandstone clasts, caliche nodules) and diagenetic constituents (right, calcareous rhizoconcretions and ferromanganese nodules) expressed as densities (counts or weights per cubic meter). The bottom two panels show magnetic susceptibility data. Low and high-frequency data are in chi units. The coefficient of frequency dependency is a unitless ratio. Note that shading is only an approximate indication of the vertical position of muddy units.

N112 E99



MAGNETIC SUSCEPTIBILITY

KMB 04

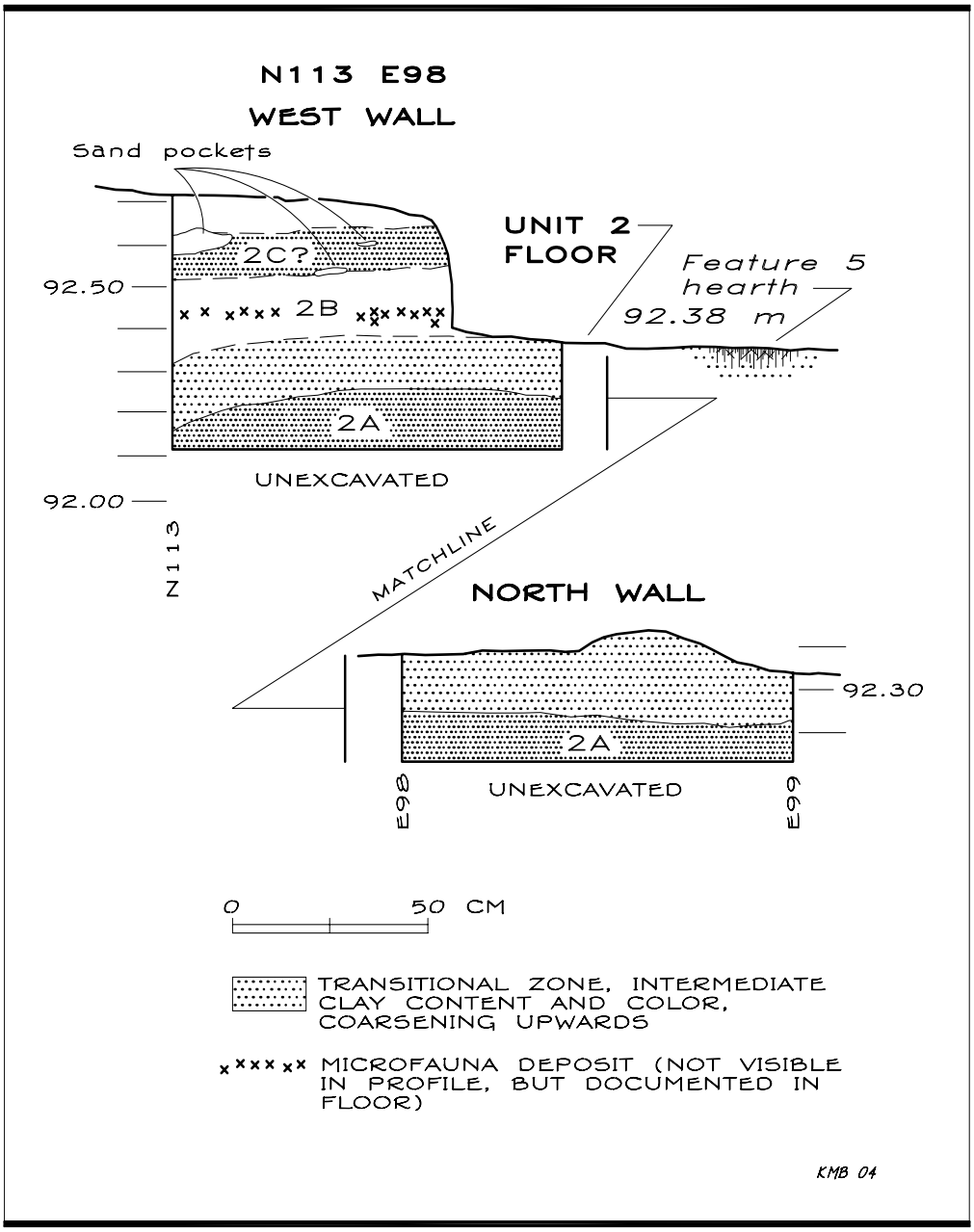


Figure 4.36. Profile of Unit N113 E98. This profile of the west and north walls also shows the vertical position of Feature 5 in schematic fashion and was drawn on the next-to-last day of field work. Note that part of the west wall has been cut away by the excavation of Unit 2 in the previous summer. The microfauna deposit associated with the hearth was not visible in the profile, but its vertical position is indicated in schematic fashion on the west wall with small "X" symbols. The transitional zone above stratum 2A was not readily identifiable in other excavation units.

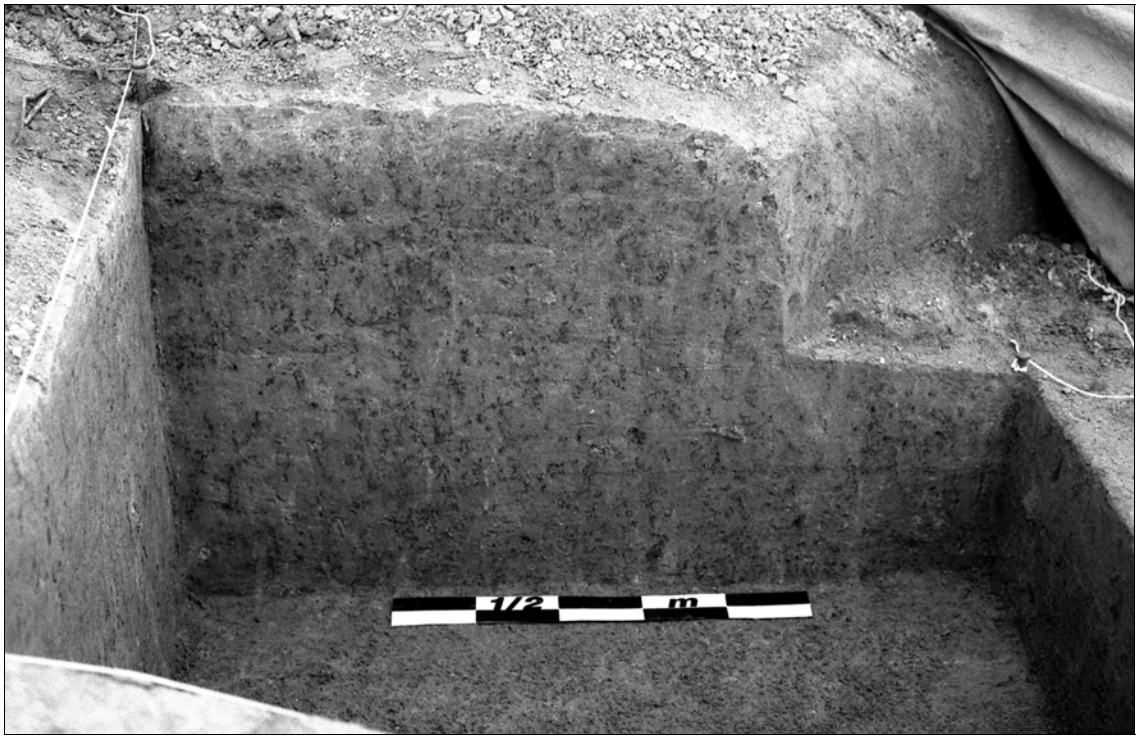
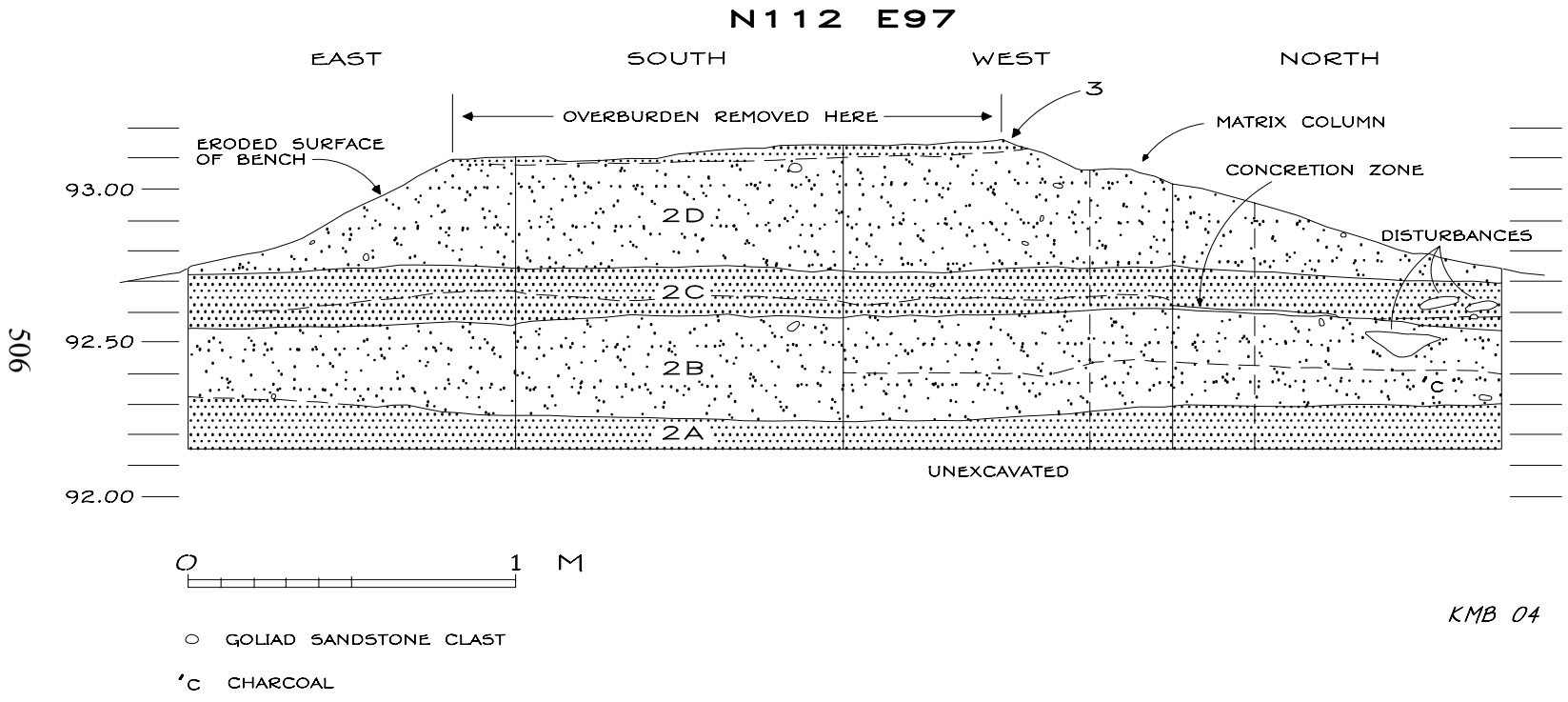


Figure 4.37. N113 E98, West Wall. Looking west at west profile wall after strata have been incised. At the right side, this excavation unit intrudes into Unit 2, dug the previous summer and not aligned with the grid system. Scale is 50 cm long.

Figure 4.38 *(following page)*. Profile of Unit N112 E97. This is a continuous, unfolded profile of all four walls of this 1 x 1 m excavation unit. Elevation in meters is shown on the left. The top boundary has been partly modified by removal of overburden. The upper part of stratum 2C is slightly grayer, with a slightly higher clay content. Disturbances visible in the north wall consist of homogeneous coarse to fine sand and clay (10YR 6.5/3) and calcareous concretions. In the north and west walls, stratum 2B has a sandier upper unit and a more clay-rich lower unit.


N112 E97
EAST
SOUTH
WEST
NORTH
3
OVERBURDEN REMOVED HERE
MATRIX COLUMN
ERODED SURFACE OF BENCH
CONCRETION ZONE
93.00
2D
DISTURBANCES
2C
92.50
2B
'C
2A
UNEXCAVATED
92.00
0
1 M
KMB 04
GOLIAD SANDSTONE CLAST
'C CHARCOAL

506

Figure 4.39 *(following page)*. Profile of Unit N109 E96. This is a continuous, unfolded profile of all four walls of this 1 x 1 m excavation unit. Elevation in meters is shown on the left. The top boundary is an artificial surface created by removal of overburden.

The much greater stratigraphic complexity of this unit is due to gravel bars and other colluvial inputs evidently arriving from the nearby buried valley wall, but many more isolated sandstone clasts are also visible, compared to the other excavation units. Most of this was probably created by exposure and erosion of Goliad Sandstone bedrock. Stratum 2D can be divided into three subunits. The top unit ($2D_3$) is lighter, with fewer Goliad sandstone clasts; unit (unit $2D_2$) is grayer, with more sandstone and snail shells; unit $2D_3$ has less sandstone and snail shells but more clay than $2D_1$ (Feature 7 could possibly have originated from this unit).

The following features are keyed to numbers shown on the profile:

1) a small zone with slightly more tan clayey sand and no cultural debris
2) a gravel lens embedded in stratum 2B
3) a lens of distinctive, homogeneous tan silt found in the southwest corner (sampled for magnetic susceptibility) unlike sediments elsewhere in the bench
4) a thin lens of gravel lying atop the stratum 2B basal contact
5) a mineralized bone fragment lying atop the aforementioned lens
6) a small patch of clean tan sand in the fill of Feature 7
7) a unit of fine sand atop the gravel bar below
8) a lens or bar with pockets of coarse sand and pebbles in a matrix of clean to muddy loose sand, thinning and rising slightly eastward, embedded in stratum 2A
9) sandy western end of lens "10."
10) another lens or bar of randomly oriented (?) chert and sandstone pebbles and clean coarse quartz sand, with ferromanganese nodules evidently formed in place after deposition of the bar. Clastic material is coarser than lens "8."
11) a cream-colored stain in unit $2D_1$.
12) a lens of tan-gray clayey sand with ferromanganese concretions at the base of unit $2D_1$.
13) small lens of gray sandy clay, caliche nodules and chert gravel, at the contact between strata 2A and 2B.
14) possible disturbance (?) consisting of slightly grayer sandy clay with snail shells, sandstone nodules, ferromanganese concretions in stratum $2D_3$; a small pocket of snail shells occurs in the middle.

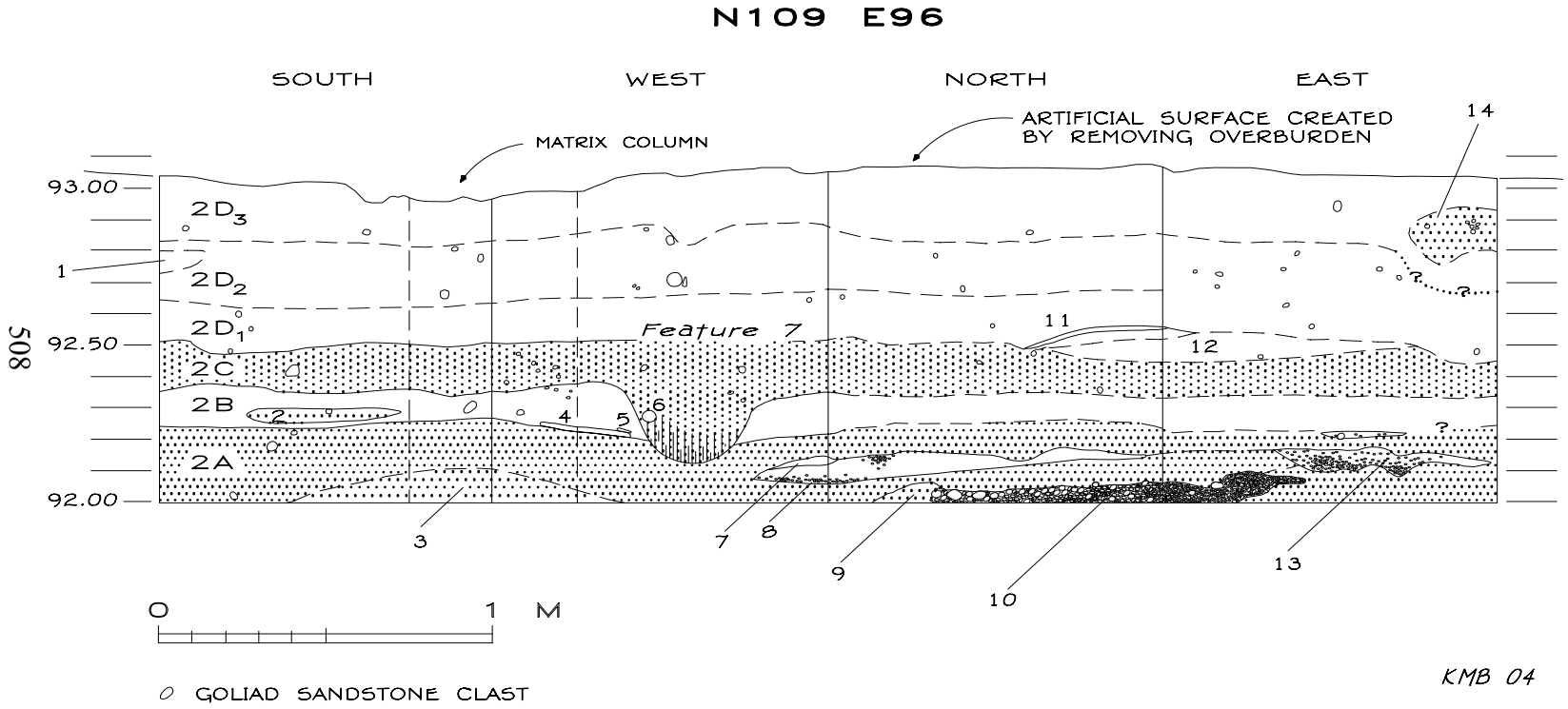
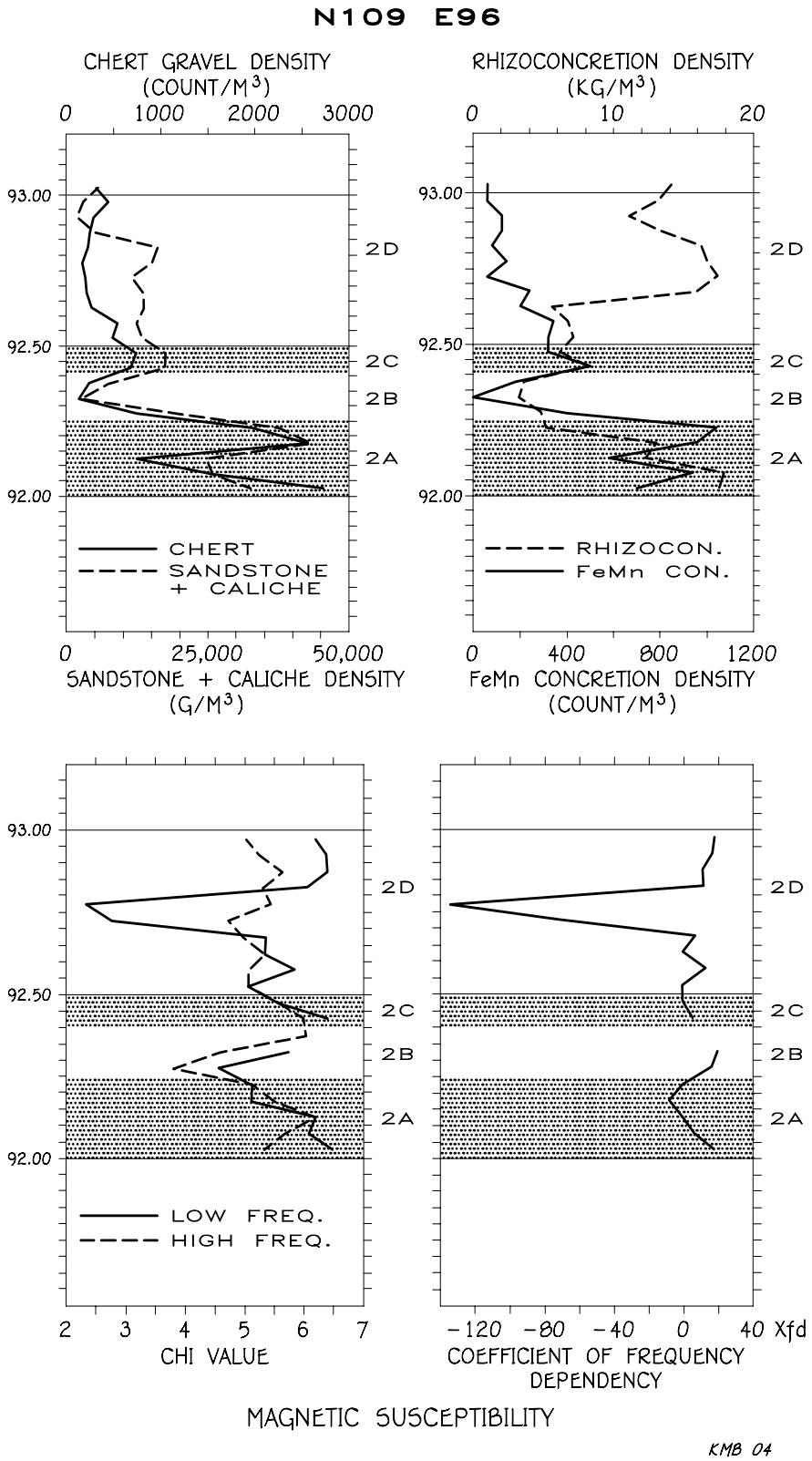

N109 E96
SOUTH
WEST
NORTH
EAST
MATRIX COLUMN
ARTIFICIAL SURFACE CREATED BY REMOVING OVERBURDEN
93.00
92.50
92.00
508
2D3
2D2
2D1
2C
2B
2A
Feature 7
1
2
3
4
5
6
7
8
9
10
11
12
13
14
0
1 M
GOLIAD SANDSTONE CLAST
KMB 04

Figure 4.40 *(following page)*. N109 E96, Stratigraphic Plots of Screened and Magnetic Susceptibility Samples. The top two panels show vertical double-axis plots of clasts (left, chert gravel, Goliad sandstone clasts, caliche nodules) and diagenetic constituents (right, calcareous rhizoconcretions and ferromanganese nodules) expressed as densities (counts or weights per cubic meter). The bottom two panels show magnetic susceptibility data. Low and high-frequency data are in chi units. The coefficient of frequency dependency is a unitless ratio. Note that shading is only an approximate indication of the vertical position of muddy units. Note also that the scales on the top left and bottom right panels differ significantly from those in most of the other plots. Coarse clastic material is more abundant in this unit than in the others.


N109 E96
CHERT GRAVEL DENSITY
(COUNT/M3)
0 1000 2000 3000
RHIZOCONCRETION DENSITY
(KG/M3)
0 10 20
93.00
92.50
92.00
2D
2C
2B
2A
CHERT
SANDSTONE
+ CALICHE
RHIZOCON.
FeMn CON.
0 25,000 50,000
SANDSTONE + CALICHE DENSITY
(G/M3)
0 400 800 1200
FeMn CONCRETION DENSITY
(COUNT/M3)
LOW FREQ.
HIGH FREQ.
2 3 4 5 6 7
CHI VALUE
-120 -80 -40 0 40 Xfd
COEFFICIENT OF FREQUENCY
DEPENDENCY
MAGNETIC SUSCEPTIBILITY
KMB 04

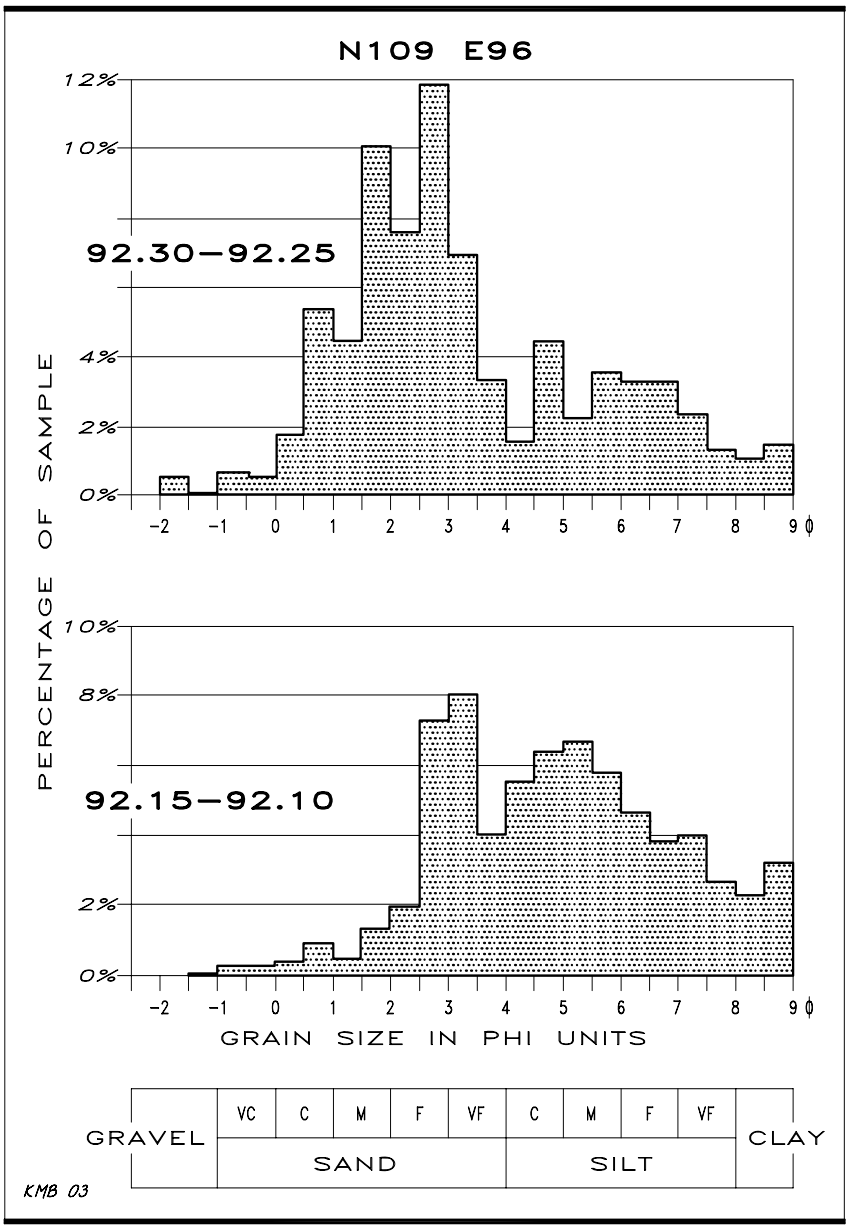
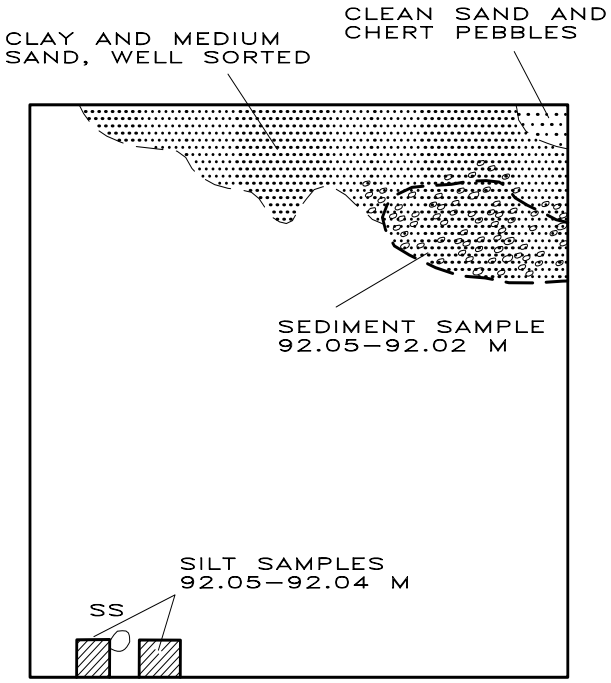


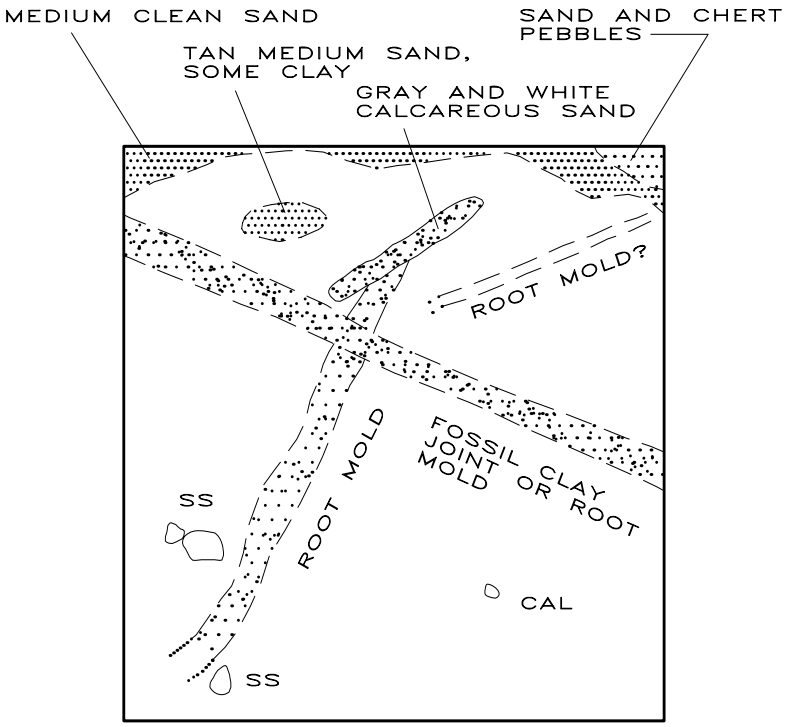
Figure 4.41. Grain-Size Samples from N109 E96. Shown here are two grain-size samples from the most southwesterly excavation unit. The sample at 92.15-92.10 m is from stratum 2A, a muddy unit, while the one from 92.30-92.25 m is from stratum 2B, a sandy unit. Note the differences in sand and silt content and peakedness. Note that only the two coarsest grades of clay were analyzed; there is an infinite tail of unanalyzed clay grades on the right side of each histogram. The key shows the Wentworth classification (VC = very coarse, C = coarse, M = medium, F = fine, VF = very fine) and the vertical scale, the height of each histogram bar in terms of percentage of sample.

Figure 4.42. N109 E96, West Wall. Floor lies at 92.00 m, profile pins visible about midway up the corners lie at 92.50 m. Feature 7 pit fill is faintly visible in section, cutting into stratum 2A above and toward right end of scale. View looking west, February 17, 1980.

Figure 4.43 *(following page)*. N109 E96 Floor Plans, 92.05-92.00 m. The lower floor plan was drawn at 92.00 m and shows only small remnants of outwash deposits along the north wall. The upper plan is for the 92,05-92.00 m level and shows location of silt and gravel samples



N109 E96 92.05–92.00 M



N109 E96 92.00 M FLOOR

KMB 04

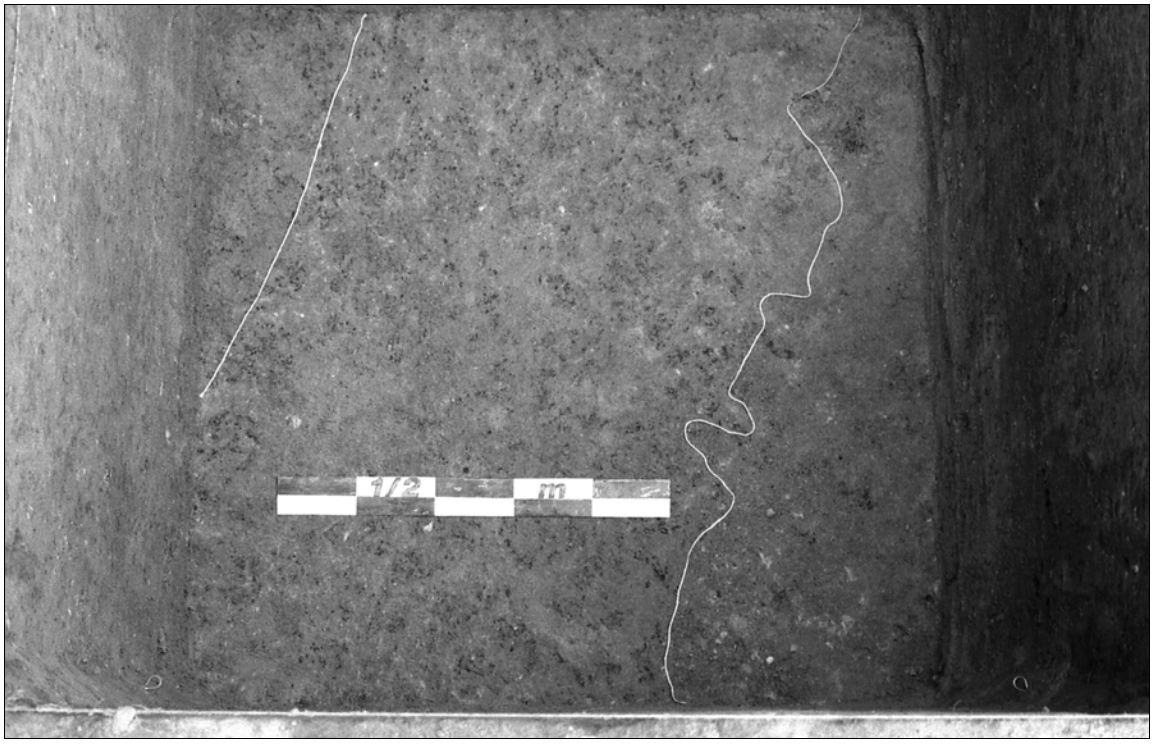


Figure 4.44. N109 E96, Looking Down and West at 92.05 m Floor. Tan silt in upper left corner, coarse outwash deposits outlined in white on right side. Compare with Fig. 4.46, lower plan. Photo January 27, 1980.

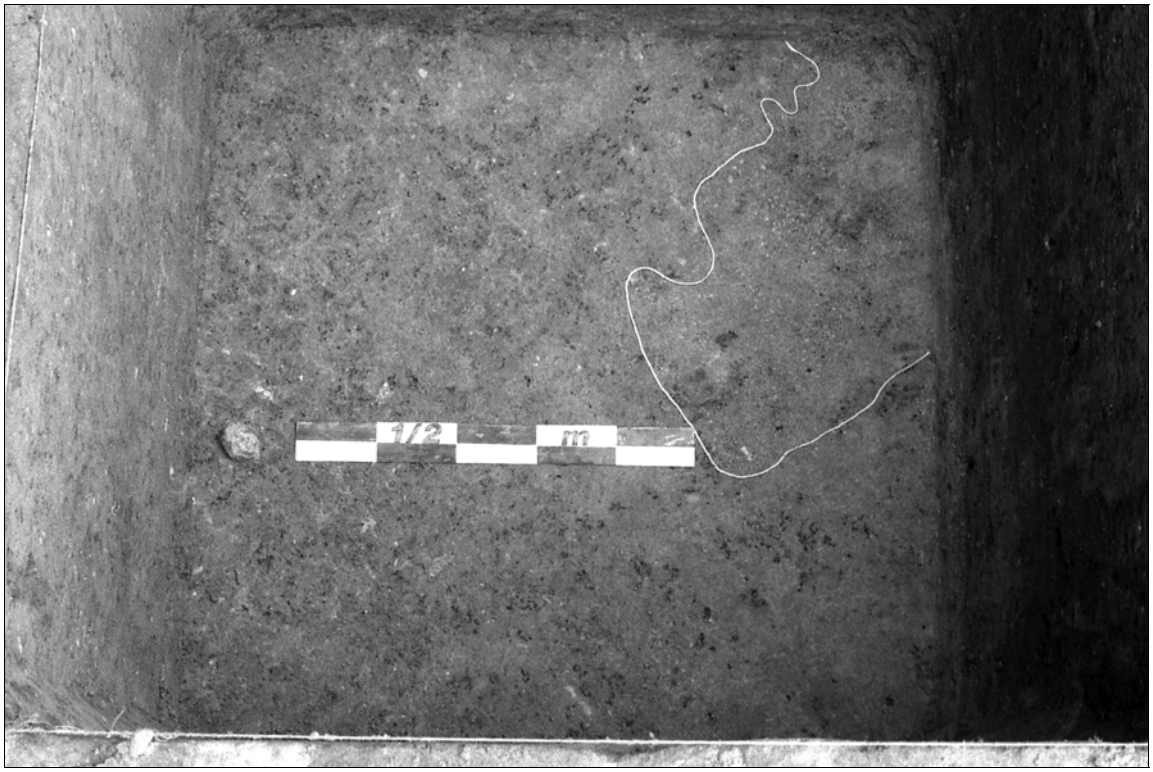
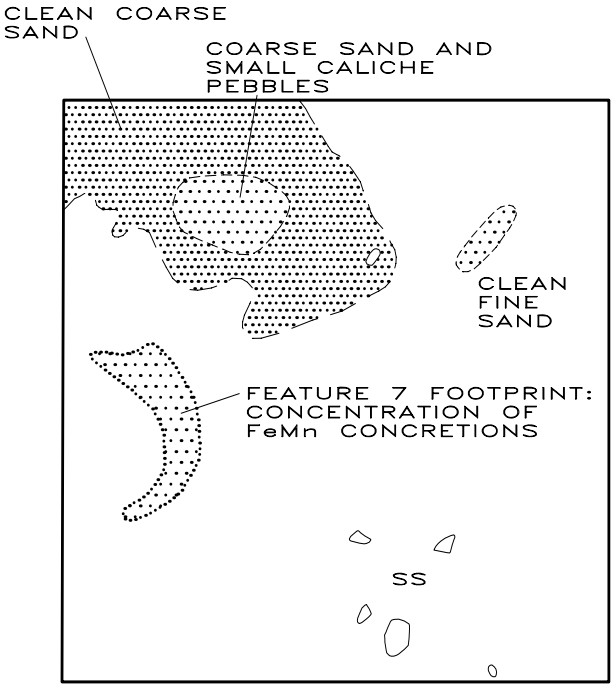
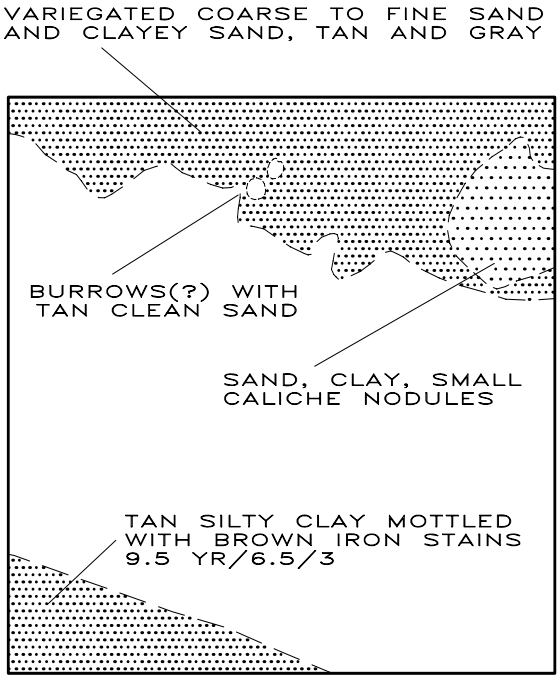


Figure 4.45. N109 E96, Looking Down and West at 92.10 m Floor. Coarse sand deposit in northwest corner is outlined in white. Compare with Fig. 4.46, upper plan.

Figure 4.46 *(following page)*. N109 E96 Floor Plans, 92.10-92.05 m. The lower plan shows outwash deposits along the north wall and a tan silt deposit in the southwest corner. The largest outwash area consists of variegated tan and gray, coarse to fine sand and clayey sand. The rest of the floor consists of light brownish-gray (10YR 5.5/2) sandy clay, mottled with dark brown ferromanganese stains and cream-colored carbonate webs. The upper plan shows a remnant ferromanganese stain from Feature 7 and outwash deposits in the northwest quadrant. The rest of the floor is similar to the one below, with some small Goliad sandstone nodules.



N109 E96 **92.10 M FLOOR**

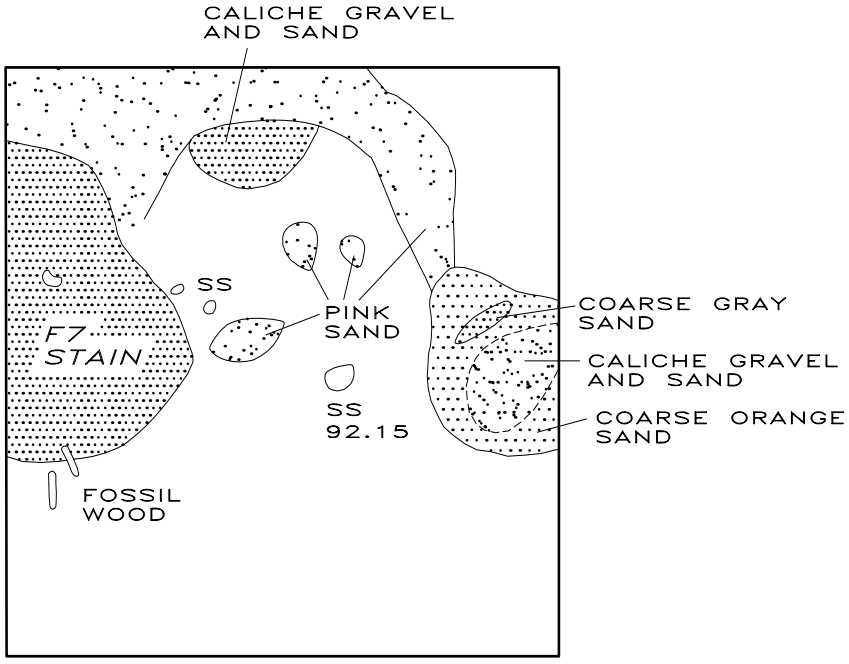


N109 E96 **92.05 M FLOOR**

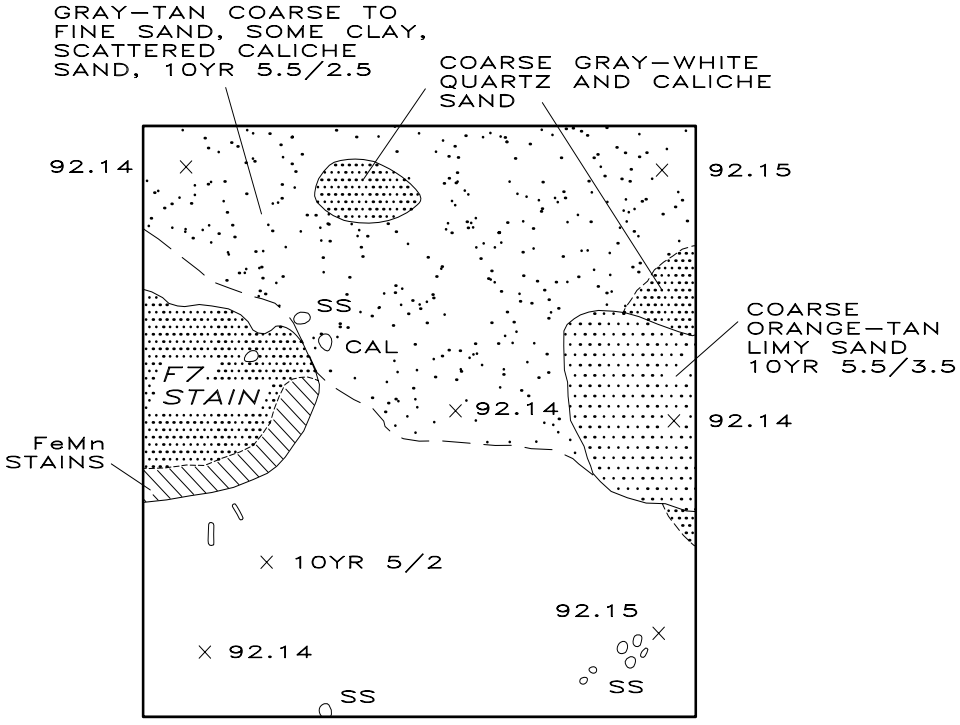
KMB 04

Figure 4.47. N109 E96, Looking Down and West at 92.15 m Floor. View of floor cleaned up after flood (compare with Fig. 4.48, lower plan, rotated 90° compared to this photo) with major features indicated. Feature 7 stain is incised at top, coarse sand deposit at bottom. Photo January 26, 1980.

Figure 4.48 *(following)*. N109 E96 Floor Plans, Two Views of 92.15 m Floor. Shown here are two views of the same floor, the upper plan drawn January 19, 1980 before flooding and the lower one drawn January 26, after post-flood cleanup. Both show remnant stains from Feature 7 along the west wall and outwash deposits along the north wall, but differ somewhat in detail. In the lower plan, the largest outwash area consists of gray-tan (10YR 5.5/2.5) coarse to fine sand with some clay (grain size is patchy) and scattered sand-sized caliche; ferromanganese concretions are less abundant and more clustered than elsewhere. The south half of the floor is light gray (10YR5/2) variegated sandy clay with carbonate stains and moderate quantities of scattered ferromanganese concretions.



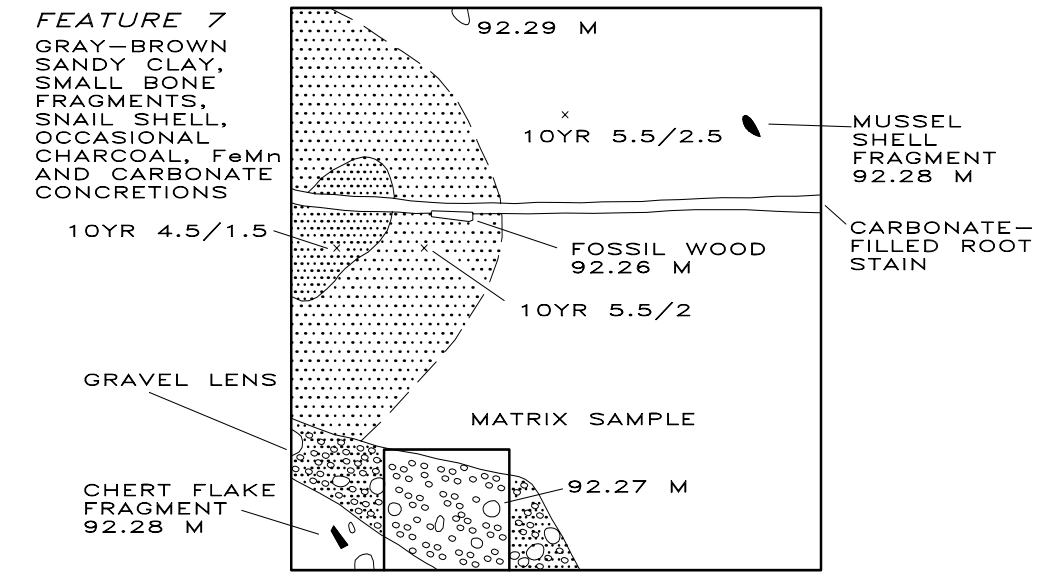
N109 92.15 M FLOOR
E96



N109 92.15 M FLOOR
E96

KMB 04

Figure 4.49 *following page)*. N109 E96 Floor Plans, 92.30-92.20 m. The lower plan shows a remnant outwash lens along the east wall, and the base of Feature 7 (haloed by a transitional zone) along the west wall. In the upper plan, the eastern lens is gone, but a coarse-grained lens of outwashed material appears in the southwest corner. It consists of mixed small (3 cm and under) Goliad sandstone nodules and chert pea gravel (the former more abundant than the latter), randomly oriented. It lacks ferromanganese stains, but otherwise the matrix is the same as most of the rest of the unit: light gray-brown (10YR 6.5/2) clayey sand with occasional snail shells present. The 92.27 m elevation shown refers to the base of one of the larger sandstone nodules in this gravel splay. In the 92.30-92.25 m level, the matrix sample normally collected from the southwest corner was shifted eastward to avoid a flake fragment found in place.


FEATURE 7
GRAY–BROWN SANDY CLAY, SMALL BONE FRAGMENTS, SNAIL SHELL, OCCASIONAL CHARCOAL, FeMn AND CARBONATE CONCRETIONS
92.29 M
10YR 5.5/2.5
MUSSEL SHELL FRAGMENT 92.28 M
10YR 4.5/1.5
FOSSIL WOOD 92.26 M
CARBONATE–FILLED ROOT STAIN
10YR 5.5/2
GRAVEL LENS
MATRIX SAMPLE
92.27 M
CHERT FLAKE FRAGMENT 92.28 M
N109 E96
92.30–92.25 M

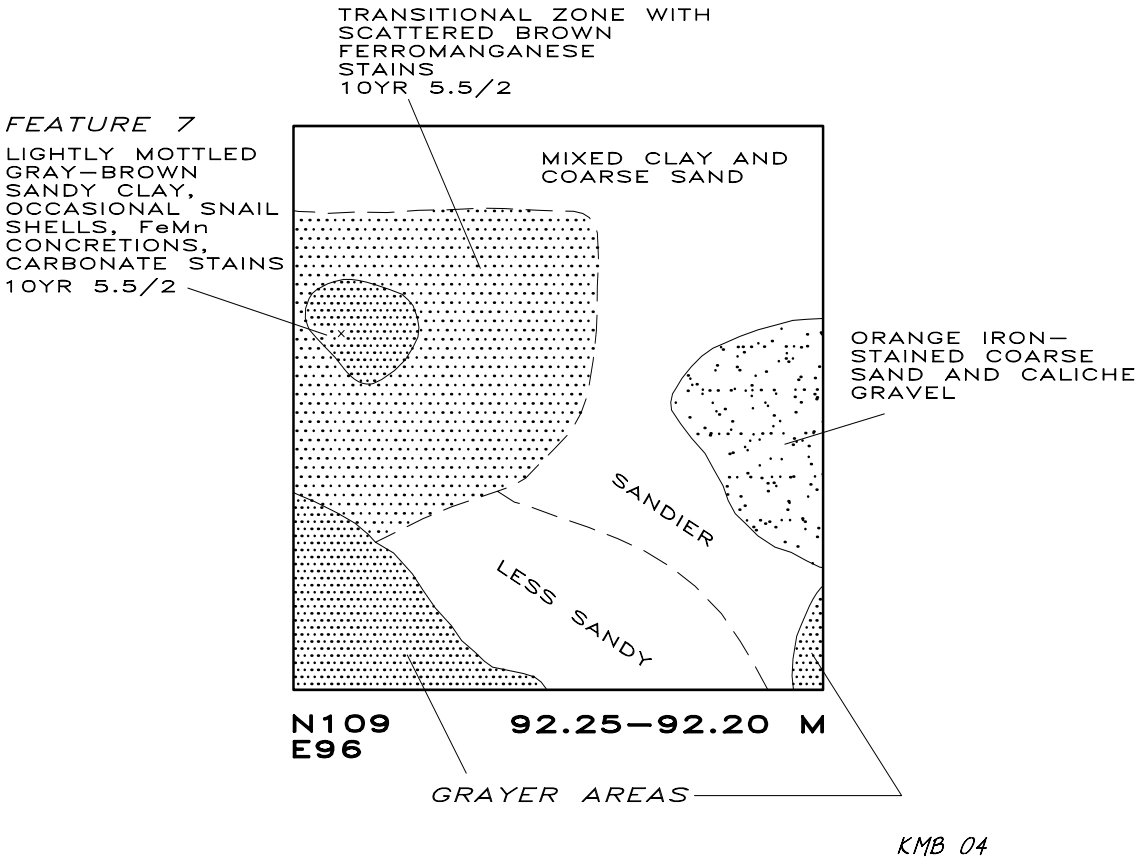
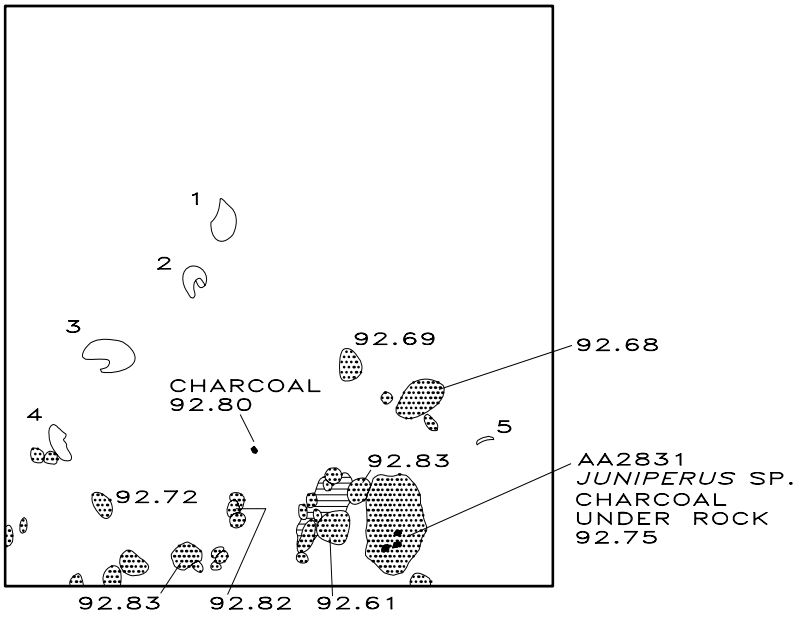
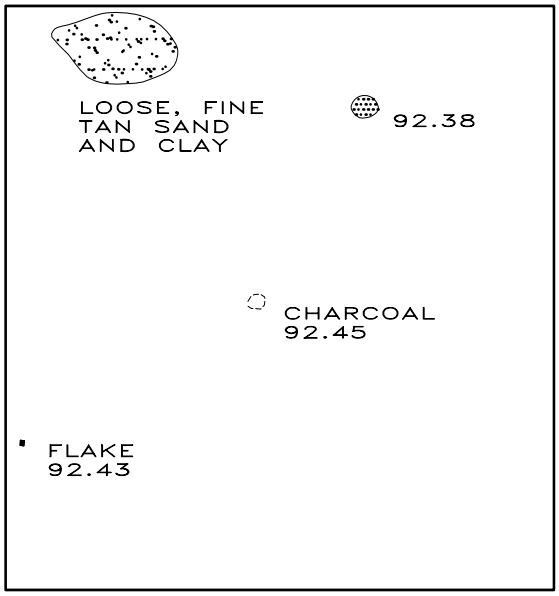

TRANSITIONAL ZONE WITH SCATTERED BROWN FERROMANGANESE STAINS 10YR 5.5/2
FEATURE 7
LIGHTLY MOTTLED GRAY–BROWN SANDY CLAY, OCCASIONAL SNAIL SHELLS, FeMn CONCRETIONS, CARBONATE STAINS 10YR 5.5/2
MIXED CLAY AND COARSE SAND
ORANGE IRON–STAINED COARSE SAND AND CALICHE GRAVEL
SANDIER
LESS SANDY
N109 E96
92.25–92.20 M
GRAYER AREAS
KMB 04

Figure 4.50 *(following page)*. N109 E96 Floor Plans, 92.80-92.60 and 92.45-92.40 m. Upper panel is a composite plan of Goliad sandstone, mussel shell, and charcoal in four different excavation levels. Numbered *Amblema plicata* valves are as follows: 1, right valve, 92.62 m; 2, smashed left valve with old break, 92.69 m; 3, right valve, 92.62 m; 4, left valve, 92.68 m; 5, an unidentified fragment, 92. 75 m. Charcoal sample (AA2831, 9880±90 BP) was collected from underside of sandstone slab. Lower panel shows small lens of outwashed sand in northwest corner at 92.40 m.



N109 E96 **92.80—92.60 M COMPOSITE**



N109 E96 **92.45—92.40 M**

GOLIAD SANDSTONE CLAST

MUSSEL SHELL

CALCRETE PAN

KMB 04

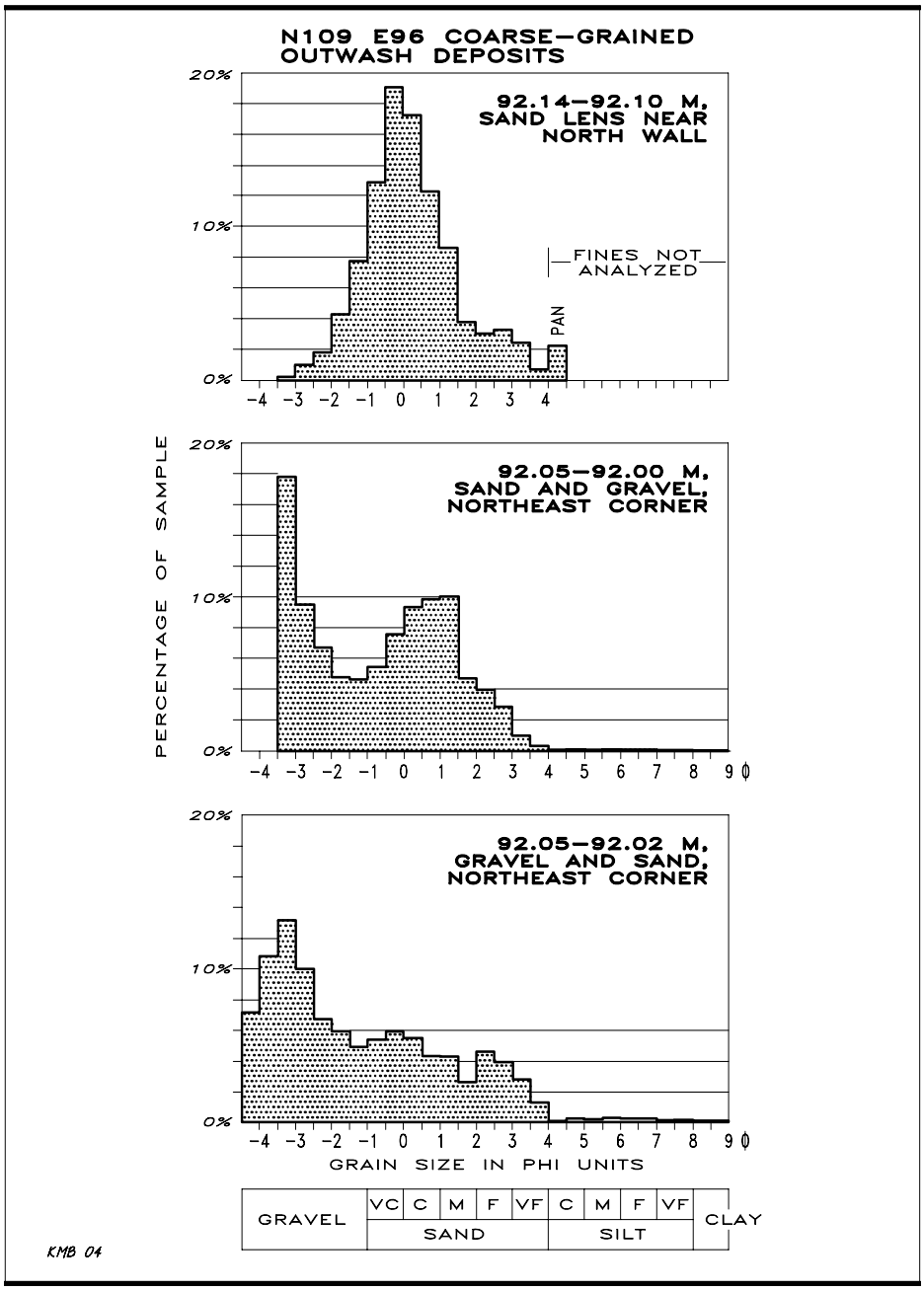


Figure 4.51. N109 E96, Grain-Size Histograms for Coarse-Grained Outwash Deposits. Top panel, quartz and caliche sand lens near north wall (approximately 92.14-92.10 m; see Fig. 4.48); silt and clay were not analyzed for this sample; rightmost bar represents pan fraction. Middle panel, clean sand and gravel from extreme northeast corner (92.05-92.00 m; see Fig. 4.43). Lower panel, caliche and chert gravel and sand, northeast corner (92.05-92.02 m; Fig. 4.43, upper plan).

Figure 4.52. N109 E96, Looking Down and South at 92.80 m Floor. This view shows part of the scatter of Goliad sandstone clasts mapped in the upper panel of Fig. 4.50 but has a different orientation and shows only one level. Scale is 50 cm long.

STRATIGRAPHY OF THE BENCH DEPOSITS

Stratum 1 (sandy unit)

The lowest stratigraphic unit exposed in the post-Beaumont sequence, this thick sandy unit extends well below the water level in the creek. The maximum thickness visible in the cutbank is about 70 cm. The upper 10-20 cm was penetrated by three excavation units, and a fourth (N110 E102) was excavated about 35 cm into it, to an

elevation of 91.55 m. Our knowledge of this stratum is therefore limited to the uppermost portion, apart from what could be observed in the cutbank. It is gray (in the upper 10 cm) to grayish-tan in color (2.5Y 5.5/2 moist). After the carbonate has been removed by acid digestion, the upper 35 cm of stratum 1 consists of about 38% sand, 30% silt, 30% clay (plus analytical error), and 1% gravel, but this characterization conceals a good deal of variability. Composition ranges as follows:

Gravel: 0 to 4.5%

Sand: 23 to 51%

Silt: 24 to 38%

Clay (plus analytical error): 24 to 40%

Note that the proportions given above (and in all of the following discussion) are for dry sediment weight after the carbonate has been removed. A single sediment sample from this stratum was submitted for radiocarbon assay (GX-18866-AMS). It comes from N111 E101 matrix column at 91.95-91.90 m and was found to be extremely low in organic content (about 0.1% after concentration; Harold Krueger, personal communication, December 28, 1991). The $\delta\ ^{13}C$ value of the humin fraction is -21.0 ‰.

Fairly abundant chert gravel was recovered from the 1/4-inch screen in this stratum (Table 4.5). Stratum 1 was not subdivided in the field, although a subtle color and grain size division was noticed in the cutbank, with the lower unit bearing a pinkish cast perhaps due to iron staining. The staining increase in an upstream direction, possibly indicating a greater proportion of reworked Lissie sediments in this direction.

Table 4.5. Material Recovered from Quarter-Inch Screen.

Average of all units except N113 E98 and N109 E96						
Stratum	**Average chert gravel density (count/m^3)**	**Average snail density (count/m^3)**	**Average rhizonconcre-tion density (g/m^3)**	**Average FeMn density (count/m^3)**	**Average Goliad SS and caliche nodule density (g/m^3)**	**Number of levels averaged**
3	2000	2168	13,634	126	2225	1
2D	2163	3180	11,524	166	1088	7
2C	570	1710	13,094	53	1040	6
2B	370	310	10,683	30	1487	26
2A	326	239	17,490	16	257	14
1	1430	10	26,068	72	918	12
Average of all units except N113 E98						
3	2000	2168	13,634	126	2225	1
2D	2626	4419	12,388	152	6249	17
2C	2210	1808	11,622	143	5164	8
2B	661	331	10,277	43	2169	28
2A	5287	199	16,358	234	8861	19
1	1430	10	26,068	72	918	12

In the sediment sample column from N110 E102, another change in the sediment occurs about 10 cm below the upper contact. Samples above 91.75 m are fine-grained and clay-rich, with little gravel present; sediment is primarily less than 2.5 phi in size, without prominent size modes. The sample from 91.75-91.70 m is a sandy, higher energy deposit with over 4% gravel, including some over 4 mm in diameter, and with a prominent size mode at 2.5-3.0 phi (Fig. 4.66). Samples below this become progressively sandier and even more strongly modal, but have less and less gravel. The uppermost stratum 1 sample can be characterized as clay-rich and poorly sorted, the lowest sample as sandy and well-sorted. The prominent size mode at 2.5 to 3.0 phi matches the dominant mode expressed in all three of the analyzed Lissie terrace samples, and may indicate that sediment below 91.75 m was partly reworked from eroding Lissie deposits upstream.

The stratigraphic change at 91.75-91.70 m was recognized in the profiles of N110 E102, but did not appear as distinct as in the sediment samples. This is the only instance in which laboratory analysis of the sediment disclosed a major stratigraphic change not recorded in profiles of the excavation units.

Prominent, discontinuous, wavy horizontal crosslaminations are visible in strata 1 and 2A in the cutbank profile, marked by cream-colored (postdepositional) carbonate staining (Fig. 4.53). While these are not thought to be channel bedforms, they could represent small scale primary sedimentary structures of some sort developed on the floodplain paleosurface -- perhaps small scale ripples or undulations. Because they are discontinuous and overlapping, they do not appear to be laminae that were originally planar but later deformed by depositional loading. Another possibility is that they are not depositional features at all, but represent fossilized wetting fronts developed in the sandy sediments by groundwater movement. In others words, these might be the calcareous equivalents of the clay lamellae that are often seen in sandy sediments as a result of seasonal fluctuation of the water table. For the four samples analyzed, carbonate makes up about 24% by weight of the raw stratum 1sediment, but the average would probably be about 28% except for missing data from two samples. Carbonate content rises from about 22% at the lowest point in the sample column to about 26% just below the calcrete zone (see stratum 2A notes). Soluble calcium carbonate is here expressed as

$$\frac{CaCO3}{\text{sediment weight} + CaCO3}$$

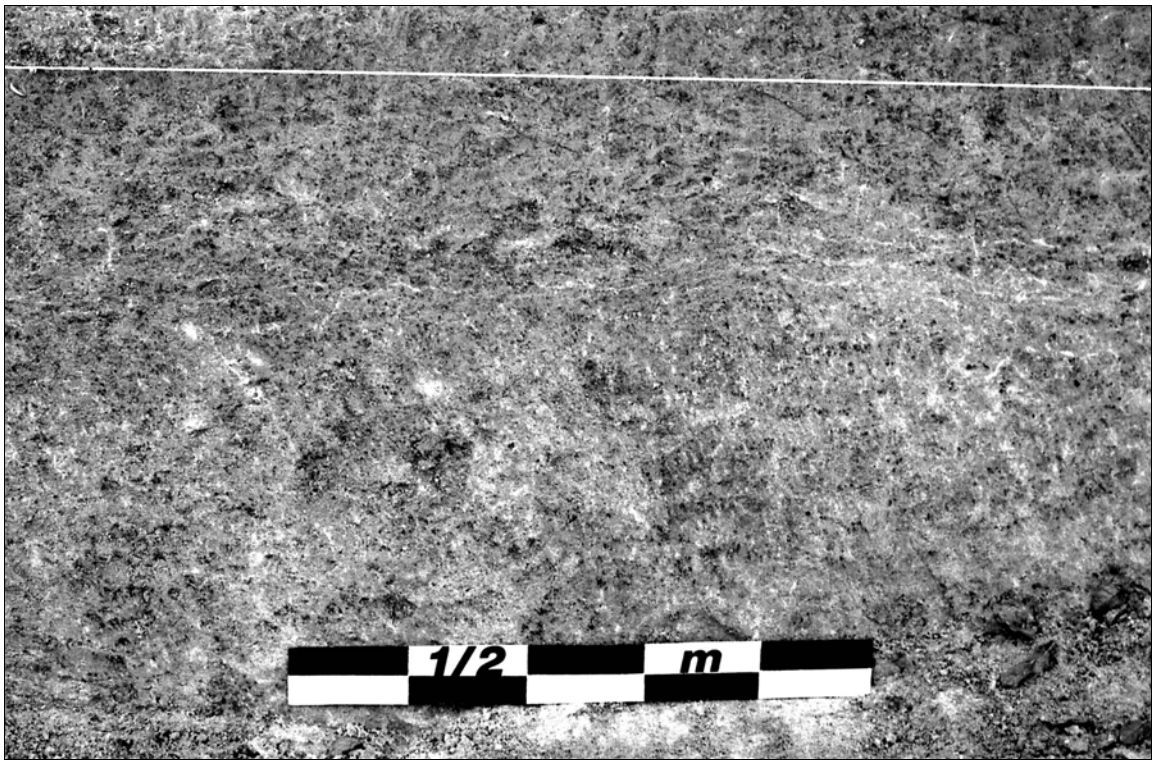


Figure 4.53. Closeup of Strata 1 and 2A in Cutbank Profile. Looking southwest at lower part of cutbank profile, near the downstream end where only the top part of stratum 1 is exposed. Top part of view is stratum 2A, and stringline is set at 92.40 m. Note wavy carbonate-impregnated laminations. Scale is 50 cm long.

Stratum 1 also contains abundant calcareous nodules and gritty, prominent cream-colored rhizoconcretions. Carbonate rhizoconcretions are very abundant in this stratum, more so than in any of the others; an average density of over 26 kg per cubic meter was calculated for stratum 1 based on screen recovery (Table 4.5). Goliad sandstone clasts and caliche nodules are less abundant in stratum 1 than elsewhere in the bench, and are actually much more abundant in the immediately overlying stratum 2A.

Large black ferromanganese concretions are also fairly abundant, more so than in the immediately overlying strata. Occasional widely scattered cultural debris [charcoal, chipping debris, small chert thermal spalls, small baked clay nodules, mussel shell fragments, a piece of charred antler or bone, and other small bones or bone fragments, including a turtle plastron (Emydidae, either *Pseudemys concinna* or *Trachemys scripta*) with cut marks; Fig. 4.54] was observed in the profiles or excavated from stratum 1, all of it within 33 cm of the upper contact. Snail shell is quite scarce in stratum 1, but inspection of surviving shells suggests that dissolution by groundwater is only partly responsible. Many of the snail shells from stratum 1 are somewhat pitted and weakened, but mechanical breakage during processing of the sediment probably accounts for most of the sample loss. Almost no shells were recovered from the 1/4-inch screen, but slightly better recovery of microsnails was achieved from the matrix samples, probably as a result of the less traumatic methods used for matrix sample processing. Two sphaeriid clams and a number of aquatic snails are present in the matrix samples from 91.85-91.80 m, and the 91.75-91.70 m sample contains a single example of the cold water spring snail *Valvata tricarinata*. *Cincinnatia integra* appears in the matrix samples from N109 E103. This slow-current aquatic snail is a diatom feeder and seems to be somewhat more common in Pleistocene than in Holocene deposits.

As in the rest of the bench sediments, pollen recovery from stratum 1 is almost nonexistent. Only scattered grains of pine, sweetgum, oak, cottonwood, Cheno-Ams, and high-spined and low-spined Compositae were recovered, along with a few fungal spores. A single dry sediment sample (N111 E101, 92.00-91.95 m) spanning the contact between strata 1 and 2A was scanned microscopically for freshwater sponge spicules at 100X. Sponge spicules and other siliceous biotic debris were found to be fairly abundant, but

fragmentary. Diatoms (mostly soil or marsh species), sponge spicules, phytoliths, and chrysophyte cysts were also abundant in the diatom samples from 91.85-91.60 m analyzed by Barbara Winsborough (see Chapter 7, diatoms). Chrysophytes are algae in the class Chrysophyceae (mostly freshwater). Aquatic diatoms are relatively abundant in strata 1 and 2A (especially the interval at 92.15-91.75 m in stratum 2A and near the top of stratum 1). Abundant freshwater sponge spicules, diatoms, some ferromanganese deposition and finely divided charcoal appear in a sediment thin section from N111 E101 (91.95-91.90 m).

Figure 4.54. Turtle Plastron Fragments (With Cutmarks) *in situ* in Stratum 1 Cutbank at 92.12 and 92.08 m, Looking Down and South. Emydidae (either *Pseudemys concinna* or *Trachemys scripta*, Lot B-154). Scale is 15 cm long.

No cultural features or concentrations of debris are known to be associated with this stratum, but a dark gray-brown stain (about 20 cm in diameter, 9YR 3.5 3.5/2 moist) consisting of clay-rich sediment mottled with burnt umber colored iron stains was discovered above the 91.90 m level in unit N110 E102 (Figs. 4.55, 4.56). The stained area was softer than the surrounding carbonate-impregnated sediment, and was still visible in the floor when the unit was discontinued at 91.55 m. It is interpreted as a buried taproot mold from a tree. A phytolith sample was collected but not analyzed.

The upper contact of stratum 1 varies in elevation from a minimum of 91.84 m in N110 E102 to a maximum of 92.24 m near the west end of the cutbank profile. Average elevation appears to be slightly above 92.00 m. The basal elevation of the stratum is unknown.

Stratum 2A (muddy unit)

This grayish brown (2.5 Y 5.5/2 to 10 YR 4.5-6.5/1-2 moist) fine grained zone overlying stratum 1 is the lowest stratum with substantial evidence of human occupation. In Figure 4.21, it is the lower and more prominent of the two dark bands visible in the cutbank. The maximum thickness exposed is about 38 cm, in the cutbank profile. It was completely penetrated by four 1 x 1 m excavation units, and the upper 15-25 cm of the stratum was exposed in three other units. It consists primarily of about 41% silt and 40% clay, with a small amount (about 19%) of sand after carbonate removal. X-ray diffraction of a clay sample from N110 E102 (92.05-92.00 m) identifies montmorillonite. No gravel was found in the grain-size samples extracted from the matrix column, although small quantities of chert gravel were occasionally recovered from the 1/4-inch screen (Table 4.5).

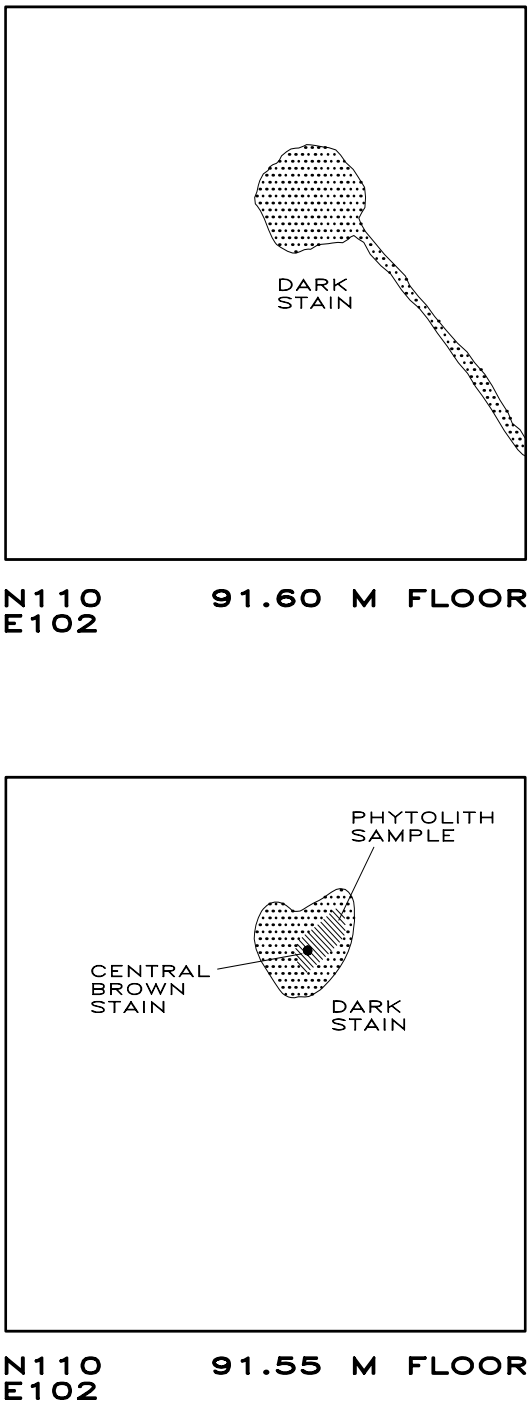
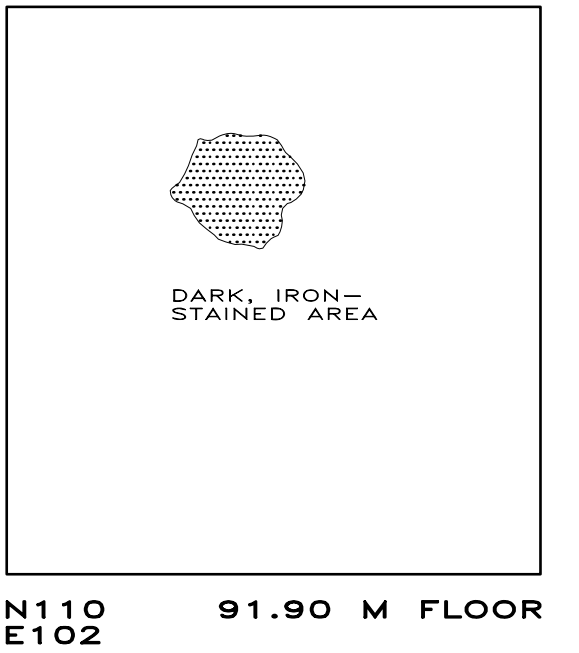


Figure 4.55. Probable Tree Mold, 91.60-91.55 m. A dark stain representing a probable tree taproot mold is shown in plan view at two different levels in unit N110 E102.



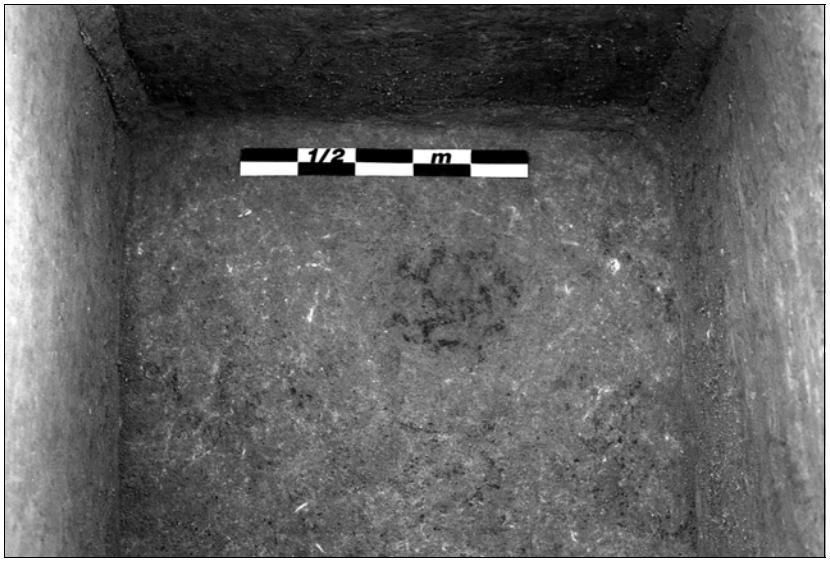


Figure 4.56. Probable Tree Mold, 91.90 m. Upper panel, a dark stain representing a probable tree taproot mold is shown in plan view about 30 cm above the preceding levels in unit N110 E102. Lower panel, photo looking down and north at taproot mold in 91.95-91.90 m level. Scale is 50 cm long.

After carbonate removal, composition ranges as follows:

Gravel: none

Sand: 16 to 24%

Silt: 39 to 42%

Clay (plus analytical error): 37 to 43%

The silt fraction is remarkably uniform in amount and size composition throughout. Fig. 4.41 (lower histogram) shows a detailed view of the grain-size composition from the 92.15-92.10 m level in unit N109 E96. Seven radiocarbon assays derive from this stratum. One of these (GX-17035-II) is from a sediment sample extracted from the matrix column in N111 E101 at 92.15-92.10 m. Organic carbon content was similar to the stratum 1 sample – about 0.21 g of carbon was extracted from 1.022 kg of dry sediment. The $\delta^{13}C$ value of the humin fraction is –18.3 ‰.

A prominent and widespread depositional surface occurs about 6-10 cm below the top of stratum 2A, marked by a scatter of mussel shells lying concave side up (Figs. 4.22, 4.30, 4.33, 4.34). When, in November 1979, we faced off and cleaned the cutbank profile for the first time, a thin band of minute desiccation cracks appeared along this surface a day or two later, as the sediments dried. Presumably this indicates a slightly higher clay content on this surface, although an increase in clay content at this level does not appear in the sediment sample column from N110 E102, nor is the surface visible in that unit. Mussel shells associated with this surface were excavated in three units, N113 E98, N112 E99, and N111 E101, and more shells appear in the cutbank adjacent to these units. All of the shells that can be definitely associated with this surface are Threeridge (*Amblema plicata*) except for a single very large partial Giant Washboard

valve (*Megalonaias nervosa*). A single Southern Mapleleaf (*Quadrula apiculata*) right valve was collected from the cutbank about 20 m downstream from the bench excavations and may also be associated with stratum 2A, but because of the distance, its assignment to this surface is uncertain. Scattered charcoal and occasional bone and chipping debris are also associated with this surface. Lenses of coarse sand and gravel also appear at this level in the excavation unit closest to the bluff (N109 E96), but are believed to represent ravine outwash deposits and are presumably unrelated to the shell-bearing surface. These are detailed below.

A second but much less extensive surface can be defined in two units only, N110 E102 and N111 E101. In the former, a hard, limey calcrete pan occupies the lower 6-13 cm of stratum 2A (Fig. 4.26). It is cream-colored to light gray (2.5 Y 6.5/2 moist) and has a gritty, cementlike consistency. Iron stains are present but not abundant. Calcium carbonate content reaches a maximum of 31% by weight in the middle of this zone (the greatest amount in any of the analyzed sediment samples) and then declines to a minimum of about 11% below the top of the zone. This limey zone is thought to be a diagenetic feature postdating the deposition of stratum 2A. The top of the zone may correspond to a shift in depositional conditions, since a small but significant amount of gravel in -1.0 to -0.5 phi size range appears at 92.05-92.00 m, accompanied by some coarsening of the sand fraction. Associated with this surface is a small charcoal-stained pit or lens (Feature 6), scattered bits of charcoal, some bone, and a small chert core. The average carbonate content for stratum 2A overall is about 19%.

A deposit of tan (9 YR 6.5/1 moist) homogeneous silt, with a slight reddish hue and fewer iron stains than stratum 2A, appears 16 cm below the top of that stratum in

the southwest corner of N109 E96. It is unclear whether this represents a unique deposit within stratum 2A, or is the upper part of stratum 1, since excavation was abandoned in the unit before this silt deposit could be identified.

Small, coarse-grained sand and gravel bars were also uncovered in stratum 2A in unit N109 E96. Because 1) these gravel bars are confined to the test unit farthest from the creek, 2) the gravel is dramatically coarser than the muddy floodplain surface on which it rests, and 3) the gravel is probably mostly derived from erosion of Goliad Formation bedrock, these bars are believed to represent outwash from small ravines or rivulets cut into buried bedrock slopes somewhere to the south and west -- bedrock that was obviously exposed when the gravel bars were forming, but is now buried by post-Beaumont terrace deposits. These localized outwash deposits are splayed outward onto the finer-grained floodplain deposits left by the creek, and they recur at intervals in strata 2A and 2B, after which they disappear. These bars can be seen in profile in Fig. 4.39 and in plan view in Figs. 4.43-4.50. The lithology, texture, and sorting of the gravel is highly variable from lens to lens. Sorting varies from unimodal (Fig. 4.51, top panel) to heavily left-skewed (two lower panels). In the three samples analyzed for lithology and texture, the largest clasts are all calcareous and are, respectively 2.0, 3.15, and 1.14 cm in maximum length. Much of the calcareous material consist of small caliche-like nodules, hard, smooth-surfaced (without adhering quartz grains), and cream-colored. Calcareous clastic material makes up respectively 29%, 49%, and 93% of the samples, and chert and quartz pebbles (perhaps also derived from the Goliad Formation) make up most of the rest (Table 4.6). The finer grades are dominated by quartz sand and silt.

Table 4.6. Lithology of Coarse-Grained Outwash Deposits, N109 E96.

N109 E96 (approx. 92.14-92.10 m), quartz and caliche sand pocket near north wall

	-4.5 to -4.0 phi	-4.0 to -3.5 phi	-3.5 to -3.0 phi	-3.0 to -2.5 phi	-2.5 to -2.0 phi	-2.0 to -1.5 phi	-1.5 to -1.0 phi	Percentage
Clastic material:								
calcareous pebbles, aggregates			1	13	64	460	2685	93.10
chert or quartz pebbles				2	7	19	197	6.83
ferruginous sandstone clasts					1	1	2	0.07
Other inclusions:								
ferromanganese nodules					2		41	
snail shell fragments							8	
bone fragments							2	

N109 E96 (92.05-92.02 m), tightly packed caliche and chert gravel and sand, northeast corner

	-4.5 to -4.0 phi	-4.0 to -3.5 phi	-3.5 to -3.0 phi	-3.0 to -2.5 phi	-2.5 to -2.0 phi	-2.0 to -1.5 phi	-1.5 to -1.0 phi	Percentage
Clastic material:								
calcareous pebbles, aggregates	7	26	57	109	191	469	1150	49.29
chert or quartz pebbles		3	36	107	200	595	1108	50.27
ferruginous sandstone clasts							1	0.02
Goliad sandstone clasts	1	2		6	5		4	0.44
Other inclusions:								
ferromanganese nodules				2	12	11	21	
snail shell fragments						1	2	
chert flake/shatter/heat spall							1	

N109 E96 (92.05-92.00 m), clean sand and gravel, extreme northeast corner

	-4.5 to -4.0 phi	-4.0 to -3.5 phi	-3.5 to -3.0 phi	-3.0 to -2.5 phi	-2.5 to -2.0 phi	-2.0 to -1.5 phi	-1.5 to -1.0 phi	Percentage
Clastic material:								
calcareous pebbles, aggregates			20	18	41	62	162	29.08
chert or quartz pebbles			7	35	69	151	454	68.71
ferruginous sandstone clasts							3	0.29
Goliad sandstone clasts				1	4	12	2	1.82
orthoquartzite pebble			1					0.1
Other inclusions:								
ferromanganese nodules				1	3	4	9	
chert flake/shatter/heat spall							1	

Microscopic examination of the finer grades of sand shows that many of the grains have whitish calcareous coatings, probably remnants of the original calcareous cement. These lenses have also been infiltrated by the same gray phreatic carbonate found elsewhere in the bench deposits. One of the samples collected at 92.05-92.00 m includes a small chunk of carbonate-cemented conglomerate (10 YR 7.5/2), with chert pebbles up to 14 mm in diameter. It seems clear that the phreatic carbonate has infiltrated the gravel lenses after they were buried in stratum 2A floodplain sediments. Small numbers of ferromanganese nodules, snail shell fragments, and bone fragments are also present. A small chert flake fragment and a shatter fragment (or heat spall) were also found in two of the samples. These appear to be cultural and have unabraded edges. Since chipping debris, bone, and snail shell were found in the overlying and adjacent stratum 2A sediments, it is possible the items found in the gravel samples were simply introduced from the adjacent sediments.

The prominent wavy crosslaminations seen in stratum 1 are also visible in stratum 2A in the cutbank profile, but were not recognizable in any of the excavations. Abundant small, dark brown ferromanganese concretions and iron stains are present, and rhizoconcretions are more abundant in this stratum than in any of the others except stratum 1. When unit N109 E96 is included in the averages, this stratum has the highest densities of chert gravel (5287 per cubic meter), ferromanganese concretions (234 per cubic meter, and caliche nodules and Goliad sandstone clasts (8861 per cubic meter), although the densities drop considerably when that unit is excluded (Table 4.5).

Material recovered from stratum 2A includes chert flakes, shatter fragments and thermal spalls, a large core-trimming flake (Fig. 3.11), a small carved and polished antler

(?) pin, fired clay nodules (some with plant impressions), small heat-discolored (?) sandstone fragments, hackberry seed fragments and animal bone [small birds, cottontail rabbit, rabbit-sized animal, a fish tooth, part of a caudal vertebra from a raccoon-sized animal, various bone fragments from rodents or other small mammals, long bone shaft fragments from deer-sized animals, some of it burned, turtle carapace fragments, packrat (*Neotoma* sp) and gopher (*Geomys* sp.) teeth]. It is worth noting that although gopher teeth were recovered from this stratum, the dense clay making up the deposit is entirely unsuitable as a substrate for gopher burrows, and it is likely that the gophers themselves were brought in from adjacent higher terraces with sandy surface soils.

A couple of small (maximum length 23.8-37.0 mm) chert or quartz pebbles that are probable manuports (unmodified geological materials carried onto the site by human agency) were found in stratum 2A. It is also likely that the small triangular chert biface (Fig. 3.11) discovered underneath Feature 5 is associated with stratum 2A, because it was recovered at 92.18 m, and stratum 2A appears to extend as high as 92.25 m in the nearby west wall profile of unit N113 E98 (Figs. 4.36, 4.37). Feature 6, a very shallow oblong pit (about 5 cm deep) 49 cm long and 18-23 cm wide originates near the base of stratum 2A, but contained only a few bits of wood charcoal, fired clay nodules, and some iron-stained snail shell. A small polyhedral chert core (Fig. 3.11) was found nearby, its base resting at 91.97 m, approximately where the lower contact of stratum 2A should be.

Snails are somewhat more abundant and diverse in stratum 2A than in stratum 1. Specimens of the cold water spring snail *Valvata tricarinata* were recovered from matrix samples in N109 E103 (92.10-92.05 m) and N110 E102 (92.05-92.00 m) and from the 1/4-inch screen in N112 E99 (92.25-92.20 m). Specimens of *Cincinnatia integra* were

recovered from matrix samples in N109 E103 and N110 E102 and from 1/4-inch screen samples in N109 E103 and N109 E96. A single sphaeriid clam valve was recovered from a transitional level at the top of the stratum (N109 E103, 92.20-92.15 m), another from midstratum (N110 E102, 92.05-92.00 m), and a single peaclam (*Pisidium* sp.) valve from a transitional level at the base (N109 E103, 92.05-92.00 m).

Scattered grains of oak, cottonwood, willow, high-spined and low-spined Compositae, and Liguliflorae (a composite, member of the sunflower family) were recovered in pollen analysis, along with some fungal spores. A single stratum 2A wood charcoal sample submitted for identification could not be identified. A small fragment of unidentified charred plant material (probably monocot, similar to a sedge or rush) was found in an un-numbered radiocarbon sample from N113 E98 (92.2092.15 m). A single dry sediment sample (N111 E101, 92.05-92.00 m) was scanned microscopically at 100 X for freshwater sponge spicules. Sponge spicules and other siliceous biotic debris were found to be somewhat less abundant and more fragmentary than in the level below, but diatoms are more abundant in this stratum than in any of the others. Diatoms, sponge spicules, phytoliths, and (in some levels) chrysophyte cysts were also abundant in the diatom samples from 92.15-91.85 m analyzed by Barbara Winsborough (see Chapter 7 on diatoms). Most of the samples from this stratum contain numbers of aquatic diatoms. Samples from stratum 1 up as high as the midpoint of stratum 2A (at 92.10-92.05 m) contain relatively high counts of *Epithemia adnata*, an epiphytic diatom characteristic of marshes and aquatic habitats. Above that level, the species becomes very scarce. A sediment thin section from N111 E101 (92.05-92.00 m) has abundant ferromanganese deposits, charcoal, diatom and sponge spicule fragments, and displacive carbonate growth pushing apart skeletal grains.

Stratum 2B (sandy unit)

This mottled gray-brown (10 YR 5.5-6.5/1.5-2.0 moist) sandy stratum is lighter in color than the adjacent strata and is quite similar in overall composition to stratum 1, with nearly equal amounts of sand (37%), silt (31%), and clay (32%), with trace amounts of gravel. X-ray diffraction of a clay sample from N110 E102 (92.45-92.40 m) indicates chlorite or kaolinite. After carbonate removal, the range of composition is:

Gravel: 0 to 0.09%

Sand: 21 to 43%

Silt: 28 to 37%

Clay (plus analytical error): 27 to 42%

Organic carbon content of stratum 2B is apparently low. A single humin sample was extracted from the N111 E101 matrix column at 92.40-92.35 m and assayed by AMS (GX-18867-AMS). The $\delta\,^{13}C$ value of the humin fraction is –22.1 ‰. Stratum 2B visibly coarsens upward, with relatively more sand in the upper portion and more fines near the bottom. This trend was perceptible in the excavation profiles, and in some cases a division into a sandier upper unit and a muddier lower unit was made. In the sediment sample column, the sand population becomes finer up to a point just above the middle of the stratum, then reverses the trend and coarsens toward the top of the stratum. The distribution of modal grain sizes is similar to the lower part of stratum 1. Fig. 4.41 (upper histogram) shows a detailed view of the grain-size composition from the 92.30-92.25 m level in N109 E96. Near the middle of the cutbank profile (Fig. 4.22), a small lens of coarse sand appears near the top of the stratum, and a stringer of pea gravel can be seen at the contact between this stratum and the overlying one. Large disturbances of unknown

origin were also visible in the northeast corner of unit N112 E99 (Fig. 4.34) and north wall of N112 E97 (Fig. 4.38)

Another characteristic of stratum 2B is the variability in thickness shown in the cutbank profile, where it varies from as little as 3 cm to as much as 19 cm in thickness (Fig. 4.22). In the excavation profiles, it is perhaps no more variable than the other strata, but it is thicker (8-43 cm) there than in the cutbank. Variability in thickness appears to be a function equally of variation in the elevation of both upper and lower contacts. This stratum was penetrated by all eight of the excavation units, making it the best sampled of the bench deposits.

The uppermost of the ravine outwash features uncovered in unit N109 E96 occurs in stratum 2B. It is a small gravel bar running diagonally across the southwest corner, composed of small Goliad sandstone and caliche nodules, mixed with some chert pea gravel in a matrix of light gray-brown clay-rich sand (Fig. 4.49). Another lens of caliche and chert gravel appears at the base of stratum 2B along the north wall of the same unit.

Rhizoconcretions are less abundant in stratum 2B than in any of the other strata, regardless of which units are averaged (Table 4.5), but small rhizoconcretions show in a sediment thin section from N111 E101 (92.40-92.35 m). Carbonate content is about 15%. The iron stains which give this zone its mottled appearance become darker, more compact, and more abundant toward the base of the stratum, where small black ferromanganese concretions appear. These concretions are not very abundant.

Small nodules of Goliad sandstone are occasionally found in this stratum, but are less common than the other strata except in unit N109 E96, which is presumed to be closer to the valley wall and therefore to the source of the clasts. If this unit is included in the averages, the situation reverses and stratum 2B has higher densities of Goliad sandstone and caliche nodules than most of the other strata (Table 4.5).

Less common are chipping debris, chert or quartzite pebbles and thermal spalls, bits of heat-discolored sandstone and poorly preserved mussel shells; rarely, bone and small bits of charcoal were encountered in the excavations. A number of small fired clay nodules were recovered. Animal bone includes gopher (*Geomys* sp.) mandible and maxilla fragments, other rodent teeth and a mandible fragment, snake and salamander vertebrae, a rabbit (*Sylvilagus* sp.) tibia fragment, fragments from unidentified rabbit-sized animals, the proximal femur of a small bird, and a urostyle from a small frog, carapace fragments from a small juvenile turtle (unidentified), unidentified small mammal bone fragments, and long bone fragments from a wolf-sized or deer-sized animal.

The principal evidence of human occupation is the hearth, Feature 5, and associated microfauna deposit; these occur at the base of the stratum, in Unit 2 and unit N113 E98. The composition of the microfauna deposit will be presented in some detail in the chapter on vertebrates. For the time being, it will suffice to say that the deposit includes a wide variety of small animals: amphibians (small mouthed salamander, ?leopard frog, toad), snakes (?ringneck, ?longnosed, brown or rough earth snake), lizards, small birds, small perch-sized fish, and a variety of small mammals, including eastern mole, hispid pocket mouse, kangaroo rat, least shrew, pocket gopher, packrat, deer mouse

or white-footed mouse, northern grasshopper mouse, vole (either pine vole or prairie vole) and cottontail rabbit. Many of these animals are fossorial and come from sandy habitats. Some come from dry habitats, but many come from damp habitats, and the fish undoubtedly derive from Coleto Creek. Both open and wooded habitats are probably represented.

Microsnails are slightly better preserved in stratum 2B (especially in the upper part) than in stratum 2A. The lower part of the stratum contains a few aquatic snails, while the top part has none except for the uppermost 1/4-inch screen sample in a few units. The cold spring snail *Valvata tricarinata* appears in unit N109 E96 at 92.35-92.30 m (three specimens). *Cincinnatia integra* continues to appear in some numbers at the base of the stratum in N109 E103 (10 specimens in the 92.25-92.20 m level) and in N110 E102 (92.30-92.25, 92.25-92.20 m). Microsnail samples at 92.55-92.40 m in N109 E103 and at 92.55-92.30 m in N110 E102 contain a concentration of *Carychium mexicanum*, a very small wet floodplain species.

Pollen is almost entirely absent from stratum 2A. Three indeterminate grains and a single grain of *Carya* sp. (most likely pecan) were recovered, but the zone from 92.35 to 92.15 m was entirely devoid of pollen. Wood charcoal from N112 E99 (92.40-92.35 m) has been identified as oak (*Quercus* sp.). Freshwater sponge spicules and phytoliths were found in most of the diatom samples from this stratum, and chrysophyte cysts were found in the lowermost sample

Diatom counts are much lower in stratum 2B than in strata 1 and 2A. Soil, marsh, and aquatic species were recovered. The sample from 92.40-92.35 m lies at the midpoint

of the stratum in unit N110 E102, and it contains higher diatom counts and species richness than the rest of the stratum 2B samples, and it includes several marsh and aquatic species not found in the others.

Stratum 2C (muddy unit)

This dark colored, muddy stratum is an analogue of stratum 2A, but is thinner and, as a unit, somewhat coarser as a result of greater proportions of sand and gravel (although the sand itself is finer than in stratum 2A). It was penetrated by seven excavation units. The average thickness of stratum 2A is roughly 18 to 29 cm, while stratum 2C is generally about 10 to 17 cm thick, but thickens downstream in the cutbank profile, to a maximum thickness of 40 cm at the east end of the bench. Stratum 2C is a mottled gray (10 YR 5.5/1.0-1.5 moist, 2.5 Y 6.5/2 dry) and brown (7.5 YR 4.5/4 moist), similar in color to stratum 2A, but more uniform from profile to profile. It has the same plastic, clay-rich appearance as stratum 2A, and consists of about 31% sand, 33% silt, and 36% clay, with trace amounts of gravel (although these averages are based on only three sediment samples). After carbonate removal, the range of variation is:

Gravel: 0 to 0.70%

Sand: 26 to 38%

Silt: 29 to 36%

Clay (plus analytical error): 33 to 38%

A sediment subsample was extracted from the N111 E101 matrix column at 92.70-92.65 m and submitted for radiocarbon assay (GX-17034-II). About 0.17 g of carbon was extracted from 1.129 kg of sediment The $\delta^{13}C$ value of the humin fraction is –19.0 ‰. More chert gravel was recovered from the 1/4-inch screen than in strata 2A and

2B (Table 4.5). The composition of stratum 2C is somewhat intermediate between that of 2A and 2B; a grain size mode at 2.5 to 3.0 phi is represented in stratum 2B but is not shown in stratum 2A. The upward-coarsening trend of the sand fraction in stratum 2B reverses in this stratum. In unit N112 E97, a division can be made between an upper unit and a lower unit that is less gray, has slightly less clay, and in some places has slightly more concretions. This muddy unit is much fainter and less well-defined than stratum 2A. That is illustrated by photos of the cutbank (Fig. 4.21), and some of the unit profiles where the contacts could not be successfully matched in adjacent walls (Fig. 4.30) or could not be traced in some walls (Fig. 4.34, Fig. 4.36). Stratum 2C was a difficult stratum to profile in nearly all the units. At the east end of the bench, a one-meter long, thin layer of scattered pea-sized chert gravel appears at the contact between stratum 2C and 2B in the cutbank profile. Nearby in stratum 2B is a lens of coarse sand. These deposits perhaps suggest higher discharge conditions in this vicinity, but are not duplicated elsewhere at this stratigraphic position. Some small pockets of sand also appear in the north wall of N112 E97 and the west wall of N113 E98.

Calcium carbonate rhizoconcretions are much less abundant than in stratum 2A, but are more abundant than in stratum 2B. Ferromanganese concretions are also more abundant (Table 4.5). Carbonate webbing is more conspicuous in this stratum than in the overlying stratum 2D, although rhizoconcretions were nearly as abundant in that stratum. Carbonate content is about the same as in stratum 2B, or 15%. Iron stains are darker, more compact, and more abundant in stratum 2C than in the overlying stratum 2D. In unit N109 E96, Goliad sandstone clasts are more abundant than in stratum 2B, although in the remaining units, the density diminishes slightly.

Because this stratum is thin, the sample of its contents is small. A small unmodified quartz cobble (74.5 mm long) was found in unit N109 E103. Chert flakes, heat spalls, fired clay nodules, discolored sandstone, hackberry seed fragments, occasional small bits of mussel shell (none identifiable) and charcoal, and animal bone were recovered. Identifiable wood charcoal includes *Ulmus* sp. (elm) and *Carya* sp. (probably pecan). Identifiable bone includes a bullfrog (cf. *Rana catesbeiana*) urostyle fragment, frog pelvic girdle fragment, salamander vertebra, a fish tooth, fish vertebra, caudal vertebra from a packrat-sized mammal, calcined rabbit (*Sylvilagus* sp.) tibia fragments, unidentified rodent rib fragment, and a skull fragment (with cut marks) from some unidentified small animal. A chert cobble core (Fig. 3.11) and the distal left humerus of an adult raccoon (*Procyon lotor,* Fig. 4.57) were recovered from the cutbank. The latter is the largest single bone element found in the bench deposits, although it is probably not the largest animal represented.

Also possibly associated is a small, poorly defined pit (?), Feature 7. The actual surface of origin of Feature 7 is somewhat ambiguous; it could have been excavated from a surface as low as the contact between strata 2B and 2C or as high as some point within stratum 2D. Associated with this feature, both within and outside the fill, are bone fragments and small animal bones in somewhat greater than usual abundance (cf. *Dipodomys ordii*, frog, small mammal, turtle carapace). A possible chopping tool made from a chert cobble (Fig. 3.11) was recovered nearby, but at an elevation definitely below the point of origin of the feature.

Figure 4.57. Raccoon Humerus Exposed in Stratum 2C, Cutbank. Looking southwest; measuring tape ruled in inches and centimeters. This is the largest single element known from the bench deposits, although it is probably not the largest animal represented. Photo December 10, 1979.

Snails from stratum 2C are more abundantly preserved in the 1/4-inch screen sample, although microsnails are actually less abundant than in stratum 2B. Three examples of *Cincinnatia integra* were recovered from the 1/4-inch screen sample in N111 E101 (92.65-92.60 m) and N109 E96 (92.45-92.40 m and 92.40-92.35 m) and one from a matrix sample in N110 E102 (92.70-92.65 m). Other aquatic snails recovered from the 1/4-inch screen include *Helisoma anceps*, *Gyraulus parvus*, and unidentified planorbids (two examples of each).

Of the two pollen samples analyzed from this stratum, one was entirely barren, while the other contained only a single grain of low-spined Compositae and a single trilete spore.

Diatoms are as abundant in stratum 2C as in strata 2B and 2D. Evidently preservation is more or less constant for these three strata. Taxonomic composition is similar to the other strata. Sponge spicules and phytoliths are present, but not abundant.

Stratum 2D (sandy unit)

This thick, sandy stratum is perhaps the most variable (both laterally and vertically) of the bench deposits, although this variability does not show in the sediment sample column. Stratum 2D was completely penetrated by 3 m^2 of excavation units, and in another 4 m^2 the upper part had been partially removed by erosion of the bench surface. Excavation of most units began in this stratum; in only one unit (N109 E103) was it completely sealed by overlying deposits.

Stratum 2D is composed of about 51% sand, 22% silt, and 26% clay, with trace amounts of gravel; after carbonate removal, the range of composition is:

Gravel: 0 to 1%

Sand: 46 to 56%

Silt: 19 to 25%

Clay (plus analytical error): 22 to 28%

Considerably more chert gravel was recovered from the 1/4-inch screen than in the strata below (Table 4.5). This unit is characteristically mottled and variegated throughout. The mottling is caused by homogeneous gray (10 YR 6.5/2) stains, usually vertical but sometimes oblique, curving, or horizontal. These probably represent krotovinas excavated by burrowing insects, moles (?), or crawdads (although no crawdad remains have been found in the site), or perhaps they are small root molds that have filled with sedimentary fines. In some cases they have a carbonate core. These stains are present in all the bench strata, but are most visible in the sandy, light-colored stratum 2D. They are conspicuous in black and white photos (Figs. 4.28, 4.29, 4.32, 4.33), less so in black and white infrared and color. Rusty brown (7 YR 5.5/3) iron stains, lighter in color and less prominent than in the zones below, are the other source of mottling. A large disturbance of unknown origin can also be seen in the southeast corner of unit N109 E96 (Fig. 4.39).

In the cutbank profile, near Feature 5, this stratum appears relatively homogeneous (10 YR 5/4 dry), but downstream near the east end of the profile, coarse sand appears at the base, grading upward to fine sand at the top.

In two excavation units, stratum 2D was divided into three separate depositional zones, but the zones are not comparable from unit to unit. In one of them (N109 E103) a thin band about 3-7 cm thick, grayer and muddier than the rest of the stratum, appears near its midpoint, dipping slightly eastward (Fig. 4.24). This zone is very poorly defined and was not recognized until excavation of the unit was finished, and it was noticed on an overcast day when lighting conditions were especially good.

In another unit, N109 E96, stratum 2D was divided into three zones of nearly equal thickness. Here again the middle zone is slightly grayer and muddier, but is about 17-23 cm thick and is chiefly distinguished by more sandstone nodules and snail shells (Fig. 4.39). Its definition may be due primarily to debris scattered from a nearby possible hearth (see below). Again, these subzones are faintly defined and cannot really be seen in the photos of the profiles (Fig. 4.42). The following descriptions of the subzones in N109 E96, listed from the top down, are excerpted from the field notes:

Stratum $2D_3$: Variegated gray (root molds: 10 YR 6.5/1.5) and rusty brown (iron stains: 10 YR 5.5/3) clay-rich sand with calcium carbonate concretions. Fewer sandstone nodules than $2D_2$; some snail shell, occasional charcoal; lower contact indistinct.

Stratum $2D_2$: Slightly grayer than 2D3, but chiefly distinguished by more sandstone nodules and snail shell; gray-brown (10 YR 6.5/2) sandy clay with sandstone nodules about 0.5 to 2.5 cm in diameter, *Rabdotus* sp. and other snail shells (iron stained); ferromanganese stains; lower contact indistinct.

Stratum $2D_1$: Same as $2D_2$, but less sandstone and snail shell; more clay than $2D_3$. Feature 7 could originate from this zone, since stratum 2C matrix is noticeably sandier in the vicinity of Feature 7. Color is 10 YR 5.5/2.

Rhizoconcretions in stratum 2D are intermediate in density, while Goliad sandstone clasts and caliche nodules are abundant, especially in unit N109 E96. Carbonate content is about 15%, similar to the previous two strata. Ferromanganese concretions are also abundant, more so than in most of the other strata (Table 4.5).

One feature, a possible hearth, is known to be associated with stratum 2D. It consists of a cluster of 9 or more sandstone nodules discovered at about 92.75 m while clearing overburden south-southeast of N109 E96. Scattered sandstone fragments, small bits of charcoal, and some mussel shell (*Amblema plicata* left and right valves) uncovered at a comparable level in that unit (Figs. 4.50, 4.51) appear to be

associated, and also correspond in depth to stratum $2D_2$. *Juniperus* sp. charcoal (presumably Eastern red cedar) found in this debris scatter was collected for assay AA-2831 (Fig. 4.50). The rock cluster was never assigned a feature number, formally investigated, or recorded. Its location is indicated on Fig. 3.1, and Fig. 3.7 shows the general area. Feature 7, also located in N109 E96, could conceivably have originated from the base of stratum 2D, but is considered more likely to be associated with stratum 2C.

Material recovered from stratum 2D includes chert chipping debris, heat spalls or shatter fragments, fired clay nodules, heat-discolored sandstone, calcined snail shell, hackberry seed fragments, and charcoal.

Animal bone recovered from stratum 2D includes cottontail rabbit (*Sylvilagus* sp., mandible, tooth, astragalus, scapula, ilium, tibia fragments and possibly a vertebra), pocket gopher (*Geomys* sp., mandible, humerus), eastern mole (*Scalopus aquaticus*) distal humerus fragment, rodent, rabbit or bird long bone shaft fragments, turtle carapace fragment, a small fish mandible fragment, rodent, snake and salamander vertebrae, and unidentified herpetofauna.

Shell preservation is evidently much better in this stratum than in the deposits below it. Only stratum 2A has larger quantities of mussel shell. Whether expressed as counts or densities, snail quantities are also high in stratum 2D – for example a density of 4439 individuals per cubic meter is estimated for all the units where snails were saved. In N110 E102, the snail counts rise dramatically in stratum 2D for both the 1/4-inch and microsnail samples. In N109 E103, counts are higher for the 1/4-inch sample, but not for

microsnails. A few specimens of probable calcareous snail egg casings have been found in the bench deposits, and one example consists of some egg casings found inside an adult *Anguispira strongylodes* shell in N109 E96 (92.85-92.80 m). These are extremely delicate and thin, and illustrate the excellent preservation of much of the biological material, at least from the upper part of the bench sediments. At least six examples of *Cincinnatia integra* are known (three from matrix samples in N110 E102, and three from 1/4-inch samples in other excavation units), as well as one example of *Valvata tricarinata* from stratum $2D_1$ and another from stratum $2D_2$ in unit N109 E96. A single sphaeriid clam valve was recovered from the 92.60-92.55 m level in N109 E96. Diatom counts are low (and species richness is relatively low) in stratum 2D. The identified taxa are mostly the same soil and marsh species found in the preceding strata, with a few aquatic species. Phytoliths and a few broken sponge spicules were also found in the diatom samples. Biosilica is scarce in a sediment thin section from N111 E101 (92.80-92.70 m). The three pollen samples analyzed for stratum 2D contained a single grain of pine, 31 high-spined Compositae grains, a fungal spore, and a couple of indeterminate grains. One sample contained no pollen at all. A small piece of unidentified tree resin, sap, or amber was found in the coarse fraction of the sieved bulk matrix from N109 E96 (92.75-92.70 m, stratum $2D_2$). Remnants of carbonate coating suggest this item is contemporaneous, and not a modern contaminant. Several sap-producing tree species in the Cupressaceae or Fabaceae can be found in the region today.

Stratum 2E (sandy unit)

Directly overlying stratum 2D, and bordering the bench area on the downstream side, is a coarse sandy deposit about 30 cm thick, designated stratum 2E (Figs. 4.22, 4.58). Its elevation range in the cutbank is 93.52-93.18 m.

Figure 4.58. Stratum 2E Sediment Sample Column. Looking south at short sample column in cutbank. Note gravel lens in mid-column. Visible part of scale is about 13 cm long. Photo December 29, 1979.

Because it appears rather easily eroded and is completely absent over the bench itself, I assumed at first that it had formerly covered the bench area but had been removed by erosion. However, in the few profiles of stratum 3 available, it can be seen that stratum 3 merges uniformly with stratum 2D underneath, with no visible erosional contact. This suggests that stratum 2E is a lens of limited extent which pinches out

somewhere to the southeast of our excavations (it first appears in the cutbank about 16.5 m downstream from Feature 5). Its extent downstream is unknown, since the cutbank profile was not faced off far enough in that direction to reveal its limits; but it is not thought to be extensive.

Stratum 2E consists of relatively coarse sand with scattered pea-sized chert gravels and occasional pockets of gravel or coarser sand. It has a slight yellowish tint (10 YR 6.5/3.5) and is lightly mottled with iron stains. Ferromanganese concretions are uncommon. The single sediment sample completely analyzed (Fig. 4.59, collected from the cutbank at 93.40-93.35 m) consists of 3% gravel, 64% sand, 13% silt, and 19% clay (plus analytical error) after carbonate removal; it includes gravel from a small lens about 10 cm thick encountered in sampling, and therefore does not accurately represent the composition of the sample as a whole. Grain size modes evident in this sample closely match those shown in the stratum 2D samples; there are modes at –2.5 to –2.0, 0.5 to 1.0, 1.5 to 2.0, and 2.5 to 3.0 phi. Carbonate content can be approximately estimated at from the grain-size sample about 7% (this procedure is not quite as precise as that used for the other bench samples, but should be reasonably close).

Another sample collected at 93.45-93.40 m was partially analyzed, and includes about 10% gravel and 67% sand (the fines were not analyzed); modal structure is similar to the first sample. Carbonate content of this sample was about 8%, and the coarsest sieved grades contained significant numbers of rhizoconcretions. No cultural debris was visible in this stratum in the Coleto Creek cutbank, and none was found during collection of sediment samples. However, no other controlled excavation has been done in this unit, so we cannot be sure that it is sterile.

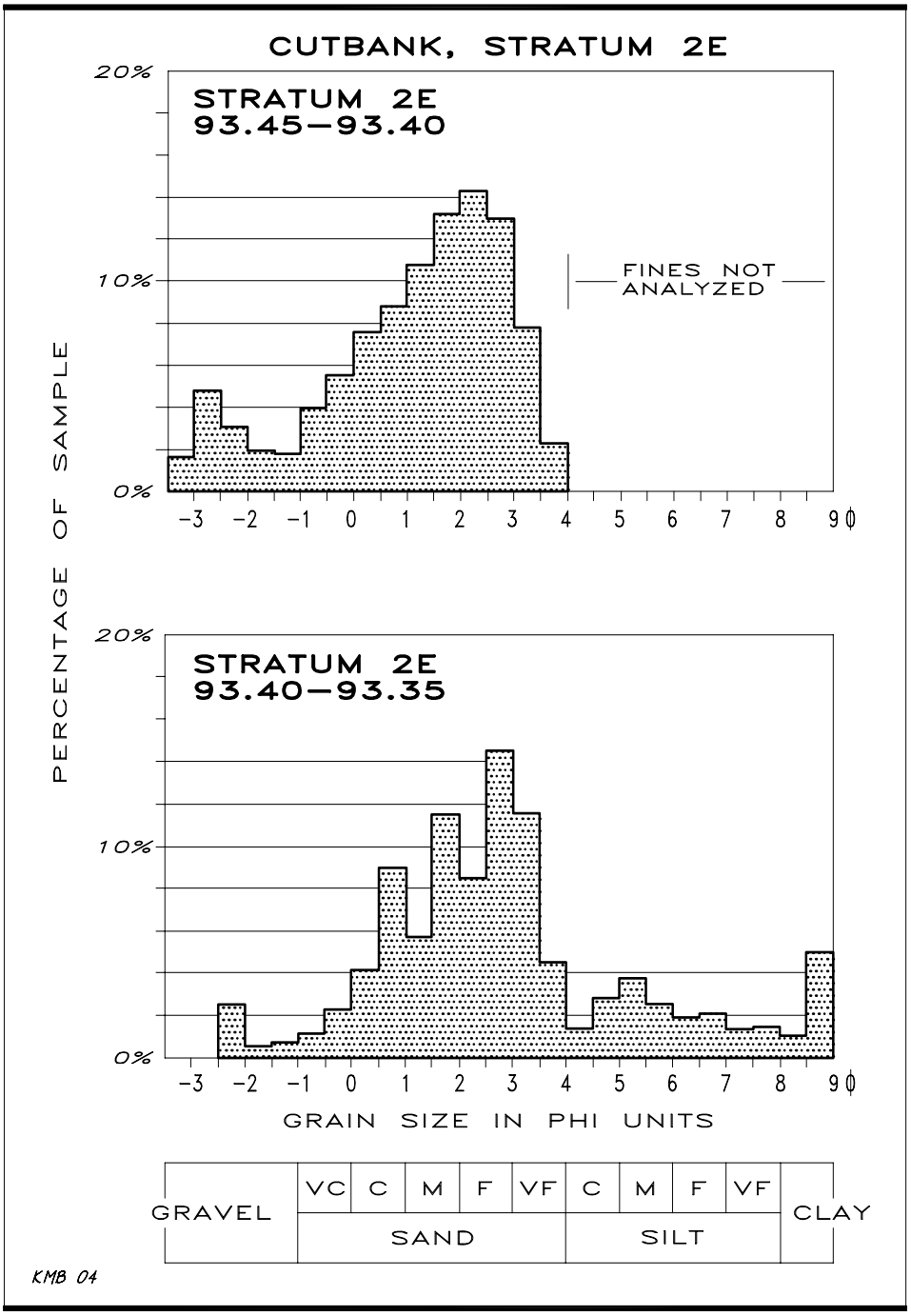


Figure 4.59. Grain-Size Histograms for Stratum 2E. Only sand and gravel grades were analyzed for the top sample. For the lower sample, analysis was done by sieving of coarse fraction and pipette analysis of silt and clay fractions; only the two coarsest clay grades (8.0 to 8.5 and 8.5 to 9.0 phi) were determined individually.

The gravel pockets embedded in stratum 2E are its most striking feature. Where these have washed out of the cutbank, they show up as voids (for example, at the top of the photo in Fig. 4.21). The large voids seen in Fig. 4.20 probably correspond as well. The coarse, sandy-gravelly nature of stratum 2E, and its limited extent tend to suggest it might be the result of a single, rapid depositional event. It cannot be a crevasse splay since the creek has never had well-developed natural levees. An alternative thesis would be that it represents bedload deposits from channel migration over the site, but this can probably also be ruled out since the contact between strata 2D and 2E appears gradational rather than disconformant. Probably the most plausible explanation is that stratum 2E represents coarse-grained overbank sediment deposited during flooding. It does not, however, have the preponderance of calcareous clastic debris seen in the ravine outwash deposits excavated in N109 E96, so the sediment source must be Coleto Creek itself rather than the nearby ravine. It is possible that stratum 2E might simply be a coarse-grained channel-margin facies of stratum 3, but I have classified it as part of stratum 2 because it more closely resembles those sediments.

No excavations were done in stratum 2E, except for the short matrix sample column 22 cm wide collected from the cutbank profile. Four samples were collected: 93.45-93.40, 93.40-93.35, 93.35-93.30, and 93.30-93.25 m. Only the upper two were analyzed for grain size, and the 93.45-93.40 m sample for diatoms. The diatom count (15) and species richness (5 taxa) are both very low. No information on bone, shell, charcoal, pollen, rhizolith, caliche nodule, or sandstone clastic content is available, though the remaining samples have been archived. Although no radiocarbon assays are available, the deposit is presumed to be early Holocene in age since it is stratigraphically higher than an apparently valid early Holocene assay (AA2831) from stratum 2D.

Stratum 3 (muddy/loamy unit)

Stratum 3 is one of the most distinctive and easily recognized depositional units in the Berger Bluff sequence, and it may appear downstream at 41 GD 31 as well. It is a dark, chocolate-brown (when moist, but 8 YR 6.5/3 dry), snail-rich, sandy silt/clay with some carbonate webbing and a tendency to form blocky peds. Conceivably, a large part of this stratum might represent either redeposited soil or silt and clay-rich alluvium stripped from the head of the Coleto Creek catchment by early Holocene erosion, but no micromorphological studies to look for relict pedogenic features have been done. It is characterized by an abundance of sand in the "very fine" (3 to 4 phi) grade and a distinct brown tint that contrasts with the gray tint of the underlying sediments. The color perhaps suggests that groundwater saturation was beginning to diminish and pedogenic processes were beginning to prevail over redox conditions as stratum 3 started to accumulate, probably in the early Holocene, although the density of rhizoconcretions remains high.

Excavations were begun in four units just above its basal contact, so a small sample drawn from the very base of the stratum is available. However, the initial levels generally included some stratum 2D sediment. Only in unit N110 E102 was the initial level (93.08-92.90 m) confined almost entirely to stratum 3. This makes it difficult to say much about the contents. A single analyzed sediment sample (N109 E103, 93.14-92.90 m) contains about 35% sand, 33% silt, 32% clay (plus analytical error), and trace amounts (0.08%) of gravel after carbonate removal. However, significant amounts of pea gravel (estimated density, 2000 per cubic meter) were recovered from the 1/4-inch screen in the single excavation level analyzed, so gravel content in the grain-size sample may

not be representative. Goliad sandstone, caliche nodules, and ferromanganese concretions were also fairly abundant in the single excavation level analyzed. For the single sediment sample analyzed, carbonate content is high (about 22%), higher than in stratum 2D.

Elevation of the basal contact varies from as low as 92.83 to as high as 93.18 m where visible in profiles. Elevation of the upper contact was measured in four places along the walls of a notch we cut into the slip-off slope (Fig. 3.2), and here the upper contact clearly dips northeastward, toward the present creek channel, at a rate of about 6 cm per meter, from a maximum of 93.57 m to a minimum of 93.32 m. This is the only profile of any extent showing the north-south dip of any of the bench strata. The average thickness of stratum 3 is estimated at about 40 cm.

During plane table mapping of the bench, before excavations were started, I tried to map the upper contact of stratum 3 where it seemed to be exposed on the toeslope east of the notch (the lower contact was obscured by slumped fill), but the elevations are a meter higher than those given above (which are based on good exposures in various profiles). Because of this, I suspect that what was actually mapped was a muddy subunit of stratum 4, perhaps part of stratum 4B (?).

The exposed face of stratum 3 all along Berger Bluff is littered at its base with abundant snails and elongate, fragile rhizoconcretions. It is not clear whether these are actually more abundant in the basal part, or if they simply accumulated there after eroding from the face. It is clear, however, that stratum 3 probably contains the most abundant snail fauna in the stratigraphic sequence. It is unfortunate that we do not have a better sample from it. The brown, loamy texture and rhizoconcretion-littered surface

give it a very distinctive appearance. Because stratum 3 is more friable than the underlying sediments, it has been removed by erosion from the top of the bench for a distance of several meters back from the cutbank (Fig. 4.19). As a result, it is entirely absent from the main cutbank profile (Fig. 4.22), although it can be seen upstream (Figs. 4.20, 4.23), and the full thickness lay concealed under slumped sediments forming the toeslope at the rear of the bench area. Fig. 4.60 shows what stratum 3 looks like in profile. In the photo (looking southwest), Ralph Robinson is collecting a phytolith sample from stratum 3 in the wall of the notch cut into the toeslope. The location is immediately above the un-numbered possible rock-lined hearth (see stratum 2D description above). The lightly incised upper contact of stratum 3 lies just above his head in the photo. Above that is the lighter-colored sandy base of stratum 4. The level line above that is set at 94.00 m.

Downstream from Berger Bluff, at 41 GD 31 (also now inundated), a very similar depositional unit appears in post-Beaumont deposits exposed in the Coleto Creek cutbank: a chocolate-brown, clay-rich stratum with abundant snail shell (*Rabdotus* sp. and other species) and chipping debris, and some mussel shell (tentatively identified as *Amblema plicata*, *Cyrtonaias tampicoensis*, *Lampsilis* sp., and unidentified specimens, probably mostly *Amblema*). A "Victoria" point (straight-based variant) was found here at 41 GD 31 on the eroding surface (Brown 1986:Fig. 3, l). A transit shot at the base of this stratum, 253 meters downstream from the bench, gave an elevation of 93.26 m, which is slightly higher than the average basal elevation in the bench area (but consistent with the profile shown in Fig. 4.23). At approximately 175 m downstream from the bench, a cluster of thermally fractured chert cobbles was noted eroding from this stratum.

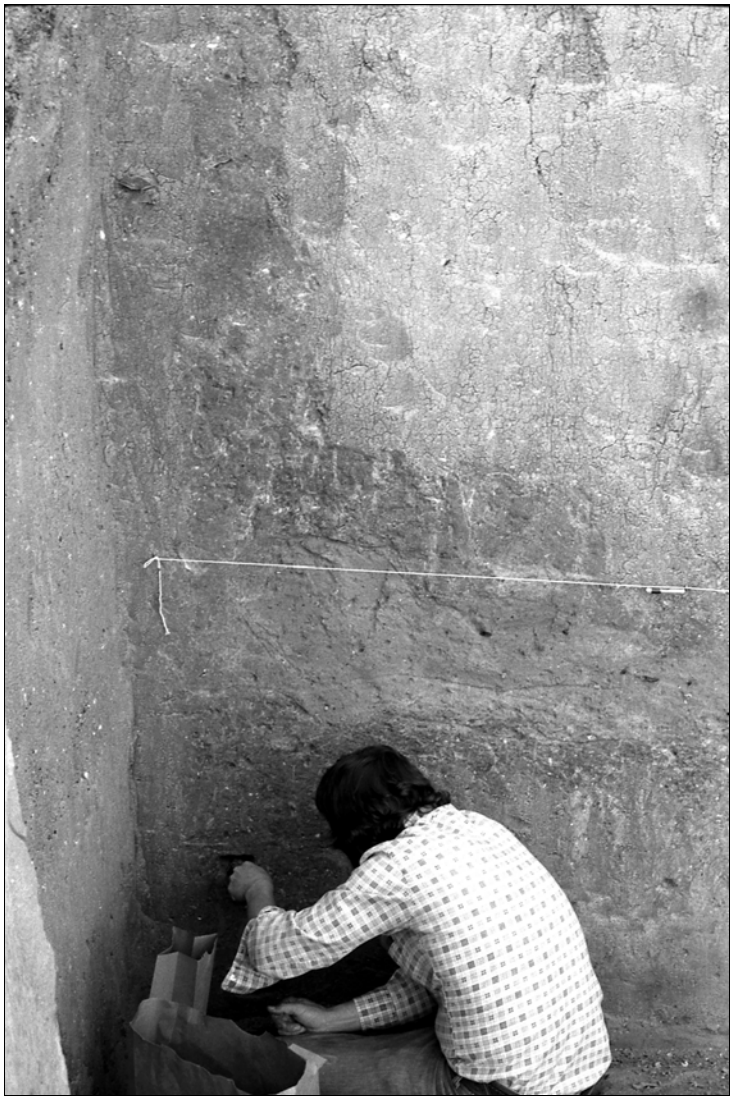


Figure 4.60. Stratum 3 and Basal Part of Stratum 4. Looking southwest at Ralph Robinson collecting phytolith samples from corner of notch cut into bluff. Stratum 3 is the dark zone whose upper contact lies just above his head; everything above that is stratum 4. Undocumented possible hearth lies under paper bag. Stringline is set at 94.00 m. Photo January 13, 1980.

A concentration of chipping debris discovered in the uppermost level of unit N109 E103 at Berger Bluff is derived from stratum 3. Many of the 41 flakes or fragments recovered match in color and texture, suggesting they are derived from a

limited set of parent cobbles. An *in situ* chipping area seems to be indicated, although no feature number has been assigned to the concentration.

The sample of animal bone from stratum 3 is very small. A couple of bone fragments (one with possible gastric rounding) from an unidentified deer-sized animal and a long bone shaft fragment from a pocket mouse-sized animal were found in unit N110 E102. In unit N109 E103, the initial level spanned both stratum 3 and part of stratum 2D, and gopher (*Geomys* sp.) mandible and maxilla fragments, a vole (*Pitymys* sp.) molar, a least shrew (*Cryptotis parva*) mandible fragment, a hispid pocket mouse *(Chaetodipus hispidus*) left femur fragment, a pocket mouse-sized calcaneum, a snake or lizard vertebra fragment, a salamander vertebra, and unidentified bone fragments from deer-sized (calcined) and rabbit-sized animals were recovered from this transitional level. A few mussel shell fragments were recovered from stratum 3, including a single valve (probably *Amblema plicata*) broken during excavation of the initial level in N110 E102. There are no pollen samples from stratum 3.

Snails are abundant in stratum 3.The density of the specimens recovered (both from the 1/4-inch screen and from the matrix samples) declines somewhat from that found at the top of stratum 2D, but is still higher than most of the rest of stratum 2D. Species richness is high in both kinds of samples. A complete mud dauber nest (possibly fired) was uncovered at 93.20 m while removing stratum 3 overburden. The location (N113.63 E94.92) is shown in Fig. 3.1. There are no analyzed diatom samples from stratum 3. The uppermost sample in the diatom column is from 92.95-92.90 m in N109 E103, and lies almost entirely in the upper part of stratum 2D.

STRATIGRAPHY OF THE UPPER DEPOSITS

During the rest of the Holocene, two massive, sandy depositional units accumulated above stratum 3. Although there are some weakly expressed variations in sediment texture in stratum 4, the depositional style can best be characterized as "massive" and homogeneous, in contrast to the cyclic nature seen in the bench sediments. Carbonate is present in these units, but it is evidently pedogenic rather than phreatic carbonate, accumulating as the regional climate became progressively drier during the early and middle Holocene.

Almost nothing is known about the middle part of the Berger Bluff stratigraphic sequence because the 4.4 meters of sediments intervening between the highest point in the bench excavations and the lowest point in David Brown's blufftop excavations remain uninvestigated, except for a narrow profile cleared for collection of phytolith samples. A section of the bluff face about 25 cm wide was troweled clean starting at the base of the notch cut into the toeslope, at about 93.06 m, and running upward to about 95.25 m. A second narrow cleared face, offset slightly east of the first, was cleared from about 95.25 m upward past the 97.50 m level. Various weakly demarcated textural zones could be seen in these two columnar profiles, but how extensive they might be is unknown.

Stratum 4 (massive sandy unit)

The original description of this stratum by Glen Evans says simply "gray, medium-grained siliceous sand – prominent vertical jointing makes this unit especially

susceptible to erosion – snail shells moderately abundant." The lower contact is located at 93.60-93.70 m in the phytolith profile, and the upper contact was drawn at 98.75-98.95 m in profiles of the blufftop excavation block (Fig. 4.61), giving it an estimated thickness of about 5.15 to 5.35 m. Its thickness is readily apparent in Figure 4.19, and its appearance can be seen in Figure 4.20. The basal part appears in Figure 4.60, from just above Robinson's head to the top of the photo, and the upper part appears in Figs. 4.61 and 4.62. Only the uppermost 1.20 m of this stratum was sampled by the blufftop excavations.

I have assigned 11 very informal subdivisions to stratum 4, based on what was visible in the narrow phytolith column profile. They may have no significance beyond the limits of the profile. From the base of the stratum upward, these are as follows:

4A: a sandy zone 30-40 cm thick (93.60-94.07 m).

4B: a thick muddy zone with caliche webbing (94.07-95.70 m); cultural debris at various levels in the upper half.

4C: a sandy zone (95.70-96.00 m).

4D: a muddy zone, sandy at base with increasing fines toward the top (96.00-96.35 m).

4E: no description recorded.

4F: a sandy zone (96.45-96.50 m).

4G: a thick sandy silt zone with carbonate (96.50-97.40 m).

4H: darker silt zone (97.40-97.57 m?).

4I: "compact buff fine sand," (about 97.57-98.50 m?), zone 4a in Brown (1983:Fig. 5).

4J: "light tan fine sand with land snail concentration" (about 98.50-98.75 m?), zone 4b in Brown (1983:Fig. 5).

4K: "tan fine sand" (about 98.75-98.90 m?), zone 4c in Brown (1983:Fig. 5).

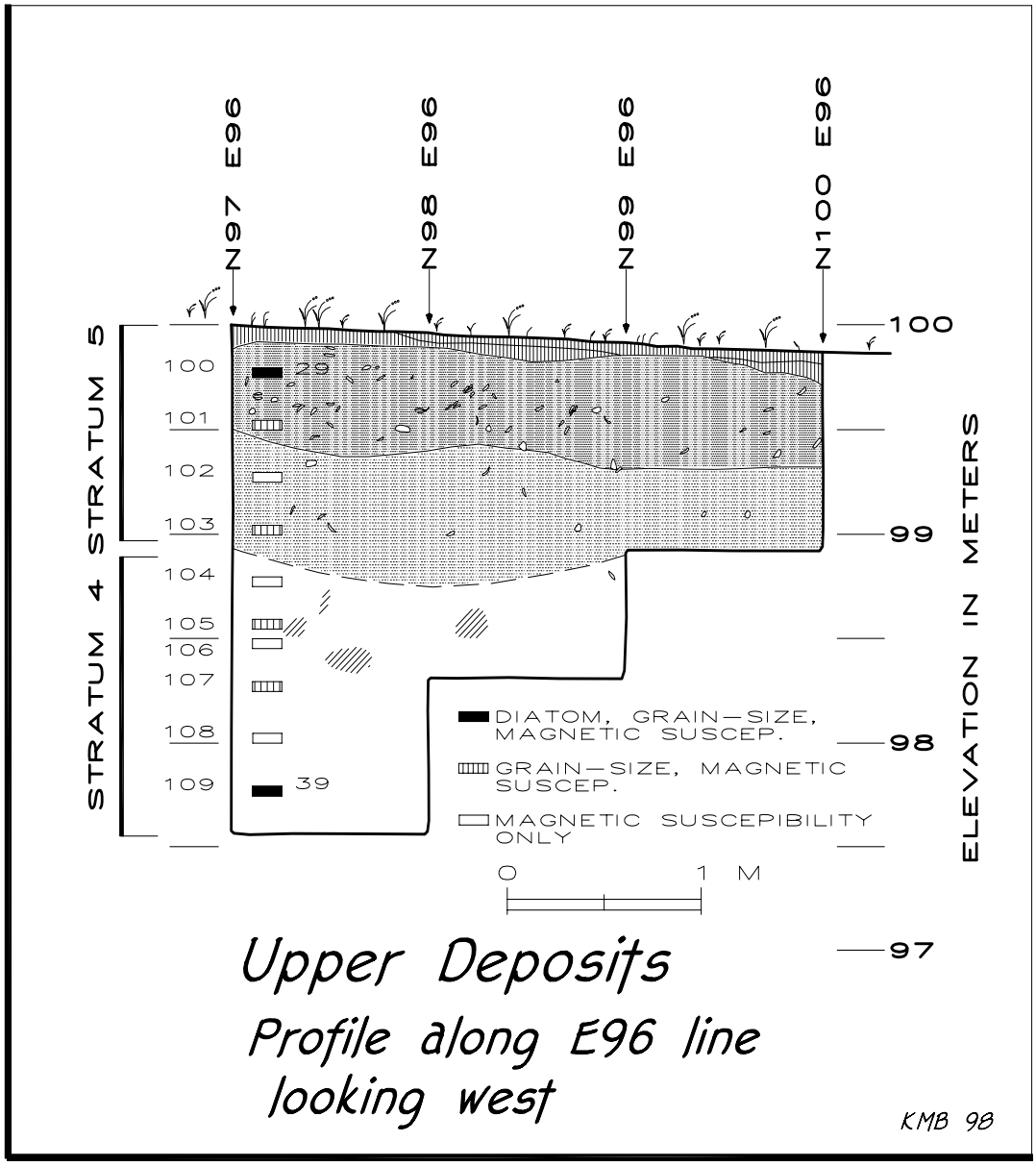


Figure 4.61. Stratigraphy of the Upper Deposits in Main Excavation Block. Shown here is the west wall of the 3 x 4 m blufftop excavation block dug in the summer of 1979. Profile similar to Brown (1983:Fig. 6), but redrawn from original field profile. Approximate location of sample column in southwest corner (collected 1981 by K. Brown and J. DeCosta) is shown. To left of the column, magnetic susceptibility sample numbers are listed; to the right, diatom sample numbers are listed for the two samples analyzed. Inclusions are mostly freshwater mussel shell, with some Goliad sandstone clasts.

Figure 4.62. Stratum 5 Profile, Looking South. View of south wall of main excavation block in the upper deposits (compare with Brown 1983:Figs. 5, 9). The floor in the left foreground corresponds roughly to the stratum 4/5 contact.

A few observations can be offered on the last three units, which are exposed in the blufftop excavation block, and which extend from 97.57 to the uneven upper contact at about 98.75 to 98.90 m. Sediment texture in this uppermost 1.2-1.4 m of stratum 4 (Table 4.7), based on three analyzed samples, consists of

Gravel: 1 to 2%

Sand: 49 to 50%

Silt: 34 to 36%

Clay: 13 to 15%

Sediment texture in both stratum 4 and stratum 5 is rather homogeneous. The sand fraction (about half of the sediment) is chiefly fine sand, well-sorted and unimodal with a prominent size mode at 2.5 to 3.0 phi (Fig. 4.63). Stratum 5 is somewhat more leptokurtic (or "peaked") and has higher skewness values than stratum 4, but otherwise the sediment textures are very similar.

Sediment color is a homogeneous beige, 10YR 6.5/1.5 dry at the base of the excavation block to 10YR 7.5/3 dry in the middle of the exposed part, to 10YR 7/1.5 dry at the upper contact. Sediment colors become progressively and steadily grayer and darker up-profile, as the dense anthrosol corresponding to stratum 5 is entered, but the consistently beige colors in stratum 4 suggest it contains very little organic content. This is supported by magnetic susceptibility values. Both low-frequency and high-frequency chi values rise dramatically from stratum 4 to stratum 5, and increase upward through the latter.

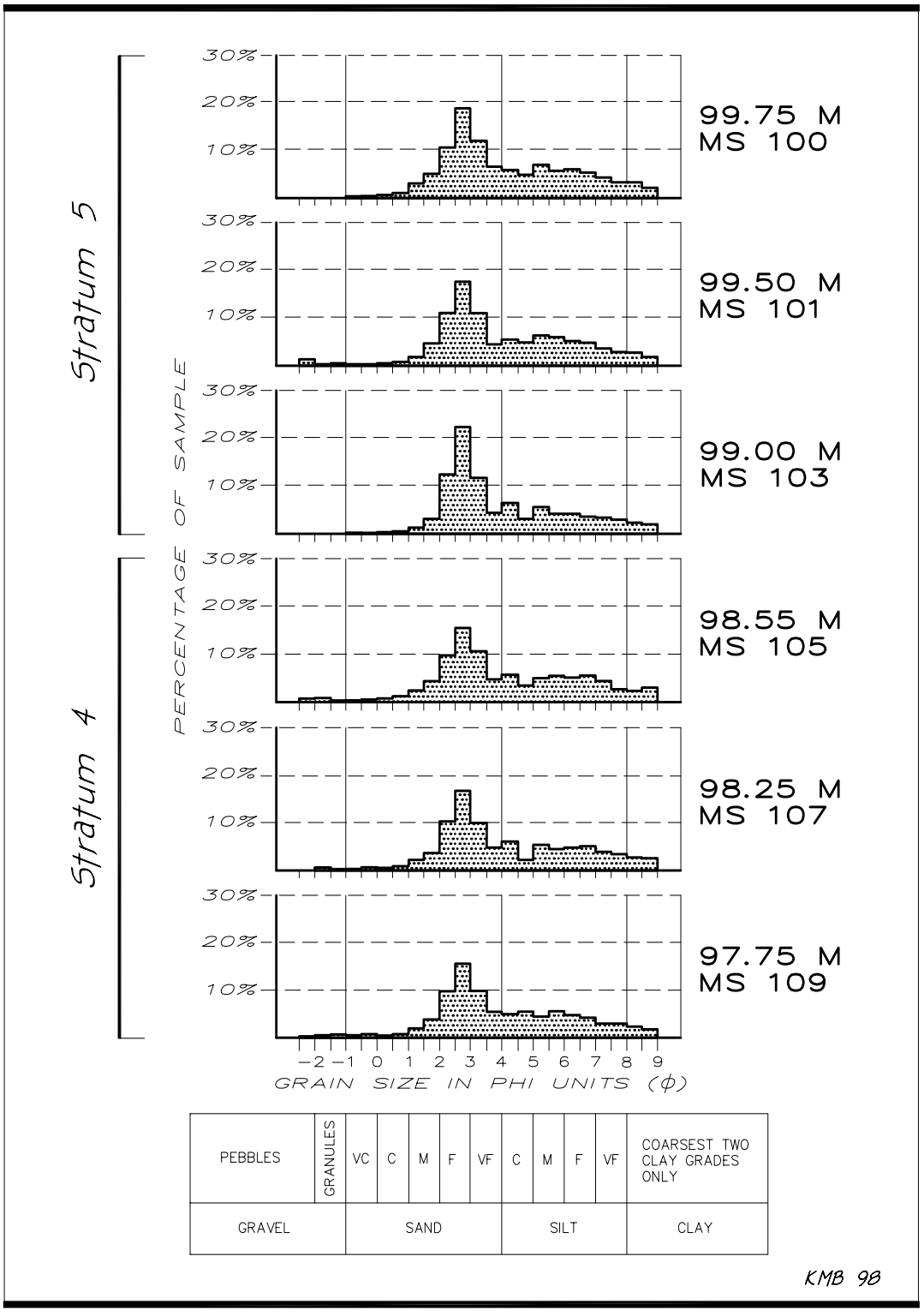
Dry sediment samples from 97.75 m and 98.45 m were scanned microscopically for freshwater sponge spicules. None were found, but the sample at 98.45 m had fairly abundant small needles, and these were also present (but in lesser abundance) in the sample from 97.75 m. These do not extinguish under polarized light, and may perhaps be dispersed pedogenic calcite needles (see Klappa 1980:Fig. 9, e, f; Wright and Tucker 1991:16). They seem to be absent from the bench deposits.

Table 4.7. Grain-Size Statistics for the Upper Deposits.

Sample	Mean Φ	SD Φ	Skew-ness	CV	Gravel %	Sand %	Silt %	Clay %
Stratum 5								
99.75	4.15	1.98	+.64	.48	0.0	56.51	39.07	4.42
99.50	4.02	2.13	+.44	.53	2.02	54.49	39.45	4.04
99.00	3.98	1.90	+.82	.48	0.0	61.27	34.64	4.08
Stratum 4								
98.55	4.10	2.26	+.28	.55	1.89	53.51	39.24	5.36
98.25	4.10	2.21	+.28	.54	1.13	55.77	37.67	5.42
97.75	4.04	2.22	+.16	.55	2.01	53.63	39.64	4.72

NOTES: Only the sample at 99.00 m was disaggregated in acid; the sample at 98.25 m contained many calcareous granules. Statistics include the two coarsest clay grades (8.0 to 8.5 Φ and 8.5 to 9.0 Φ) but not the finer unanalyzed clay grades. Clay percentage includes an error component. Percentages are recalculated to sum to 100%. Skewness and coefficient of variation are unitless statistics. SD = standard deviation; CV = coefficient of variation.

Figure 4.63 (*following page*). Grain-Size Histograms for the Upper Deposits. Shown here are grain-size histograms for three samples each from strata 4 and 5, collected from the exposed wall of David Brown's excavation block into the upper deposits. The elevation of the sample at its base and corresponding magnetic susceptibility sample numbers are shown on the right. See Fig. 4.21 for location of samples. Analysis by sieving of coarse fraction and pipette analysis of silt and clay fractions; only the two coarsest clay grades (8.0 to 8.5 and 8.5 to 9.0 phi) were determined individually. No acid digestion of samples was done Note extreme homogeneity of samples throughout both strata, presence of clay in all samples, presence of gravel in samples 101 and 105-109, and similarity in size modes to bench samples.


Stratum 5
Stratum 4
PERCENTAGE OF SAMPLE
30%
20%
10%
99.75 M
MS 100
99.50 M
MS 101
99.00 M
MS 103
98.55 M
MS 105
98.25 M
MS 107
97.75 M
MS 109
−2 −1 0 1 2 3 4 5 6 7 8 9
GRAIN SIZE IN PHI UNITS (ϕ)
PEBBLES
GRANULES
VC
C
M
F
VF
C
M
F
VF
COARSEST TWO CLAY GRADES ONLY
GRAVEL
SAND
SILT
CLAY
KMB 98

Stratum 4 also includes occasional snails and snail shell fragments, small calcareous nodules, some carbonate webbing in areas, and frequently hackberry (or anaqua?) seeds. Part of Test Pit 1, dug in 1977 and located on the north side of the blufftop excavation block, was excavated in 15 cm levels to a depth of 150 cm, and then a shovel test in the floor was dug to 190 cm. Cultural material (decreasing with depth) was found in the upper 70 cm of stratum 4 (Fox, Black and James 1979:Table 2). Unidentified turtle, bobcat, and bison bone is reported from this test pit at 120 cm and below (Fox, Black and James 1979:Table 3). The contents of two levels (1/4-inch wet screen fraction, level 14, 98.00-97.85 m and level 16, 97.70-97.55 m) near the bottom of the blufftop excavation block in unit N97 E96 were scanned carefully. Level 14 has 38 pieces of chipping debris and some thermally fractured chert or quartzite, 925 pieces of gravel (677.1 g), and no ferromanganese concretions. Level 16 has four pieces of chipping debris, a single ferromanganese concretion, and 316 pieces of gravel (233.1 g). Large and medium-bodied snail taxa include a number of *Polygyra* sp., plus *Rabdotus* sp., *Oligyra orbiculata*, *Praticolella* sp., but only one specimen of *Anguispira strongylodes*. A single diatom sample from near the base of the blufftop excavations (N97 E96, 97.75 m) was analyzed and found to be barren of diatoms, phytoliths, pollen, and sponge spicules.

There are no radiocarbon assays from this stratum, nor were any diagnostic artifacts recovered from the excavation block or test pits. Presumably, this stratum began accumulating sometime in the early Holocene and continued until the start of the Late Holocene.

From the limited information available, it appears this unit accumulated rather rapidly over the course of several millennia in the Middle Holocene. Visual evidence

suggests there is less silt and clay in the upper part of the stratum than in the lower part, which may indicate decreasing flood duration. The dilution effect of rapid accumulation rates might help to explain the apparent lack of organic matter, biological indicators, and pedogenesis, and relative scarcity of cultural debris.

Stratum 5 (massive sandy unit)

Stratum 5 is the uppermost unit in the stratigraphic sequence at Berger Bluff. It includes the dense midden under the anaqua grove at Area A, but it also extends well beyond Area A into Area B and the surrounding areas without much evidence of occupational debris. Area A is characterized by a well-developed, organic-rich contemporary soil, and along the bluff face, the overthickened A horizon extends to perhaps 2 meters or more below the surface in spots where anaqua root systems have been active (Figs. 1.34, 4.64). It is probably the local equivalent of the Copan Soil discussed by Hall (1990). In such places, the A horizon may even have incorporated the uppermost part of stratum 4. The organic matter is presumably derived from anaqua leaf litter, because there is no understory in the anaqua grove. Away from Area A, the contemporary soil is also pronounced but somewhat thinner (about 20-50 cm; Brown 1986:Fig. 4, Table 1) and seems to better developed in anaqua groves than in grassy areas. In the blufftop excavation block, stratum 5 is roughly equivalent to the A horizon and is about 1.0-1.2 m thick. Munsell colors range from buff (10YR 7/1.5 dry) at the base to gray (10YR 5/1 dry) near the surface (Table 4.8).

Figure 4.64. Looking Southwest at Excavations. Well-developed, cumulic contemporary soil developed in stratum 5 and upper part of stratum 4 caps the bluff, and is especially deep where root systems of anaqua trees have penetrated. Photo December 4, 1979.

A soil sample from a depth of 30 cm in Test Pit 1 contained 1.4% organic matter, with a pH of 8.5, but no pollen (letter of July 1, 1977, Vaughn Bryant to Anne Fox, on file at UTSA-CAR). A sediment sample from about 25 cm below the surface in the main block contained so much finely divided organic matter that grain size analysis was nearly impossible. A single diatom sample collected at 99.75 m contained no phytoliths. Dry sediment samples from 99.00 and 99.75 m scanned for freshwater sponge spicules did not reveal any spicules, although a duplicate slide from the diatom sample at 99.75 m revealed a couple of spicule fragments.

Table 4.8. Munsell Soil Colors for Strata 4 and 5, Blufftop Excavation Block.

Sample elevation (m)	Munsell color	Comments
Stratum 5		
99.90	10YR 5/1	
99.85	10YR 5/1	
99.75	10YR 5/1	hackberry or anaqua seeds
99.65	10YR 5.2/1	
99.60	10YR 5.2/1	
99.55	10YR 5.5/1	
99.45	10YR 5.5/1	
99.40	10YR 5.5/1	
99.35	10YR 5.5/1	
99.30	10YR 5.5/1	snail shell abundant here and above
99.20	10YR 5.5/1	
99.15	10YR 5.5/1	
99.05	10YR6/1.5	
99.00	10YR6/1.5	
98.95	10YR6.5/2	
98.90	10YR6.5/2	
98.85	10YR 6.5/1.5	
Stratum 4-5 transition		
98.80	10YR 7/1.5	
Stratum 4		
98.75	10YR 7/1.5	increased fines, snail shell here and above
98.65	10YR 7.5/2.5	
98.60	10YR 7.5/2.5	
98.55	10YR 7.5/3	
98.50	10YR 7.5/3	
98.25	10YR 7.5/3	
98.00	10YR 7.5/3	
97.75	10YR 7.5/2	
97.55	10YR 6.5/1.5	

NOTE: all colors recorded dry in 2004 from archived phytolith column collected in 1979 at N97.50 E96.

Microscopic calcite (?) needles are abundant at 99.00 m, but fairly scarce at 99.75 m; they are short and uniform in length.

The pronounced overthickening of the A horizon at Area A has probably occurred because sometime in the Late Prehistoric period (see chronological discussion below), sediment deposition at Berger Bluff ceased for the first time and Coleto Creek began to incise its earlier deposits, leaving a stable surface available for soil development. In addition, the soil in Area A probably qualifies as a cumulic anthrosol because of the dense midden deposits. Large quantities of freshwater mussel shell, snail shell, bone, and occasional clusters of Goliad sandstone hearthstones have probably introduced significant amounts of calcium carbonate and phosphate to the soil.

Despite the dramatic increase in organic matter in stratum 5, the sediment itself is not much different from the upper part of stratum 4. Stratum 5 has slightly more sand and slightly less gravel, silt, and clay, but the differences are very minor. Based on three analyzed samples, the sediment consists of:

Gravel: none to 2%

Sand: 50 to 55%

Silt: 31 to 37%

Clay: 10 to 15%

The mean grain size in the two strata is nearly identical. Stratum 5 is slightly better sorted and more leptokurtic (Fig. 4.63), with slightly higher skewness values, but the differences are minor. Nothing in the grain-size analysis suggests the depositional processes differ in these two units.

Stratum 5 was divided into three subunits by Brown (1983:Fig. 6): 5a, light grayish brown loamy fine sand; 5b, grayish brown fine sandy loam with midden debris; 5c, the same but culturally sterile.

How Did Stratum 5 Form?

Glen Evans interpreted stratum 5 as coppice dune deposits. His field sketch describes it as "a gradual and very slow accretion of wind-transported silt and fine sand derived mainly from the sand bars along the Coleto Creek channel, together with the decompositional organic products of herbaceous and woody vegetation. It is an aggradational soil zone overlying stream terrace deposits" (field notes, June, 1979). My interpretation differs. I believe stratum 5 represents the same sort of fluvial deposits represented by the other four strata lying beneath it. I have four reasons for arguing that stratum 5 is fluvial, not eolian in origin.

1) If there is a major change in transport mechanism across the boundary between stratum 4 and stratum 5, it is not captured in the grain-size data. The grain-size modes (Fig. 4.63) and statistics (Table 4.7) are nearly identical, at least in the upper part of stratum 4 and in stratum 5. Indeed, there is far more variability within some individual bench strata (all of which are known to be fluvial) than between strata 4 and 5.

2) Coleto Creek lies north of Area A, and in the Holocene climatic regime, the only time of year when strong northerly winds would be available to transport sand southward out of the channel is in winter. Prevailing winds from the north account for less than 6% of the year (Fig. 1.16). All of the contemporary wind-reworked sandbars at Berger Bluff lie on the north side of the creek. Moreover, stratum 5 is essentially a thick

sand sheet. It does not have the parabolic or infilled parabolic plan form usually associated with large sand bodies moved by wind, although it could also be argued this geometry would not be expected in a coppice dune anyway.

3) Although only one of the three analyzed stratum 5 grain-size samples contained gravel, the stratum is nevertheless known to contain significant amounts of scattered pea gravel. The gravel count in the uppermost 20-30 cm of stratum 5 ranges from none to a count of over 500 per m^3. Maximum densities in stratum 4 are higher (over 6000/m^3 in level 14, for example), but a density of 500/m^3 is well within the range of variation of the bench deposits (Table 4.5). All of this gravel is too heavy to have been windblown.

Some of the gravel in the upper deposits could have arrived on the screen as contamination sucked in through the water intake during wet screening (a few *Corbicula fluminea* clams about the same size as pea gravel occur in the collections, and these are definitely water-intake contamination), but I doubt this accounts a for very much of the gravel recovered on the screen from stratum 5. Incidentally, none of the gravel from the bench deposits is contamination, since wet screening was not done in bench excavations. Some gravel could have been introduced by prehistoric human occupants as contamination during mussel-collecting or water-collecting activities, but again I doubt this accounts for much of the gravel. If the gravel was introduced at the same time as the sand, silt and clay making up the deposit, it must have been brought in by running water, not wind.

4) The three analyzed samples from stratum 5 contain, respectively, about 9, 11, and 14% clay (allowing for analytical error). This is probably too high a clay content for windblown sediments (but see below). When mud is deposited by waning floodwaters in

a stream channel, it forms a clay drape over the bedload sediments. As this clay drape dries, it curls up into small, hard chips of clay that resist further size reduction. These are usually too heavy for wind transport, although some regions of Texas do have clay dunes formed by wind moving clay pellets along the ground (Price 1963; Frederick 1998). In general, though, clay is cohesive and resists disintegration into particles small enough for aerial transport unless salts are present.

Clay dunes are usually a special case, in which salt (sea salt near the coast, gypsum salts inland) makes the clay hygroscopic, and moisture breaks it into sand-sized pellets by alternate wetting and drying (Bowler 1973). The inland southeastern Louisiana Pleistocene dunes reported by Otvos and Price (2001) are an exception. Some of these have extraordinarily high silt (8.5-25.5%) and clay (4.5-22%) content, apparently derived from exposed salt-free floodplain sediments. One example cited has about 50% silt and 33% clay (Otvos and Price 2001:152), but the authors offer no explanation of how such clay aggregates could be moved by wind. In arid but non-saline continental settings, clay content of dunes is usually much lower. For example, in a dune site in Wyoming reported by Tucker (1985:Table 7), clay content ranges from 4.8-6.8%). The Muleshoe dune sands of Texas-New Mexico average roughly 3-6% (Muhs and Holliday 2001:Fig. 10). In sites like those, clay can sometimes accumulate in lamellae as a result of pedogenic processes (Muhs *et al*. 1996:138, clay content 1-7% in Colorado dunes), but there are no pedogenic clay lamellae known from any of the deposits at Berger Bluff. Based on profiles and observation while digging, the silt and clay in stratum 5 appears evenly dispersed, not concentrated in any sort of Bt horizon or in lamellae.

Perhaps the best analogy for evaluating stratum 5 as a potential coppice dune is a series of Pleistocene stream-bordering sand dunes reported from Georgia by Ivester and Leigh (2003). Here, sand seasonally blown out of sandbars and lateral bars much like the modern Coleto Creek bars formed dunes that migrated onto adjacent floodplains and were halted by vegetation. The floodplain-dune interface is marked by dramatic reduction in both clay content and coarse sand content (Ivester and Leigh 2003:Fig. 7). Dune sands had an average of about 1% clay and only 0.01% gravel. Compared to river sand, dune sediments were slightly finer, less well sorted, and had lower kurtosis values (Ivester and Leigh 2003:Table 2). The authors note that "the presence of >1% gravel or >2% very coarse sand indicates that the deposit is probably fluvial" values (Ivester and Leigh 2003:303). Comparable dunes from South Carolina have about 0.21 to 3.45% clay (Markewich and Markewich 1994:Table 1). Tested against these examples from Georgia and South Carolina, we would have to conclude that stratum 5 probably does not have the attributes of an eolian deposit.

It is easy to see why stratum 5 could be interpreted as windblown sediment. It is fine-grained (mean is about 4.05 Φ for all grades together) but poorly sorted (standard deviation about 2.0 Φ, coefficient of variation about 0.50), has low skewness values (about +0.63), has a leptokurtic, nearly unimodal size distribution, and would be very homogeneous in composition if not for the substantial addition of organic matter and cultural debris. However, many of these properties are partly inherited from the Miocene source sands in the catchment, and to some extent they probably also characterize all of the deposits that underlie stratum 5. The prominent size mode at 2.5 to 3.0 Φ seen in the stratum 5 samples also appears in stratum 4 and in many of the samples from the bench deposits. The chief difference with the bench samples is that most of them also have

several other size modes as well. Average grain size (4.16 Φ for all of the bench samples averaged together) and standard deviation (2.12 Φ, coefficient of variation 0.55) are similar, although skewness values differ. Compare the three stratum 5 samples shown in Fig. 4.63 with the three lowermost samples (91.70 to 91.55 m) shown in Fig. 4.66. All of them look very similar, even though the latter three are known to be fluvial in origin.

Stratum 5 can also be compared statistically to continental dune sands – the Georgia and Colorado stream-bordering dunes cited above, as well as worldwide sand seas summarized by Ahlbrandt (1979:Table 2; see also Lancaster 1986:Table 1). Compared to these known eolian examples, the stratum 5 sediment is finer-grained and has larger standard deviations. For the three analyzed stratum 5 samples, the mean grain size for the sand fraction only (no gravel, silt, or clay) is 2.60 ± 0.82 Φ ("moderately sorted"). Where the coefficient of variation can be computed, it is larger, except for the Georgia examples. for another comparison, the Muleshoe dune sands average about 2.5-3.0 Φ, with a standard deviation of about 0.5-0.7 Φ for sand grades only (Muhs and Holliday 2001:Fig. 9).

When Did Coleto Creek Begin Its Late Holocene Incisive Phase?

Correctly identifying the mode of deposition for stratum 5 is important, because it relates to the timing of Late Holocene hydrological change and channel incision. If stratum 5 is windblown sand, seasonal drying of the channel and incision of the channel at the beginning of the Late Holocene, perhaps around 3000 RCYBP are probably implied. On the other hand, if stratum 5 is fluvial in origin, as I have suggested, continued overbank deposition of sand until some time in the Late Prehistoric is probably implied, with major hydrological changes and channel incision occurring then, rather than earlier.

No radiocarbon assays are available from stratum 5. The age of the deposit can only be estimated from a few time-diagnostic artifacts recovered from the blufftop excavations. A single Morhiss point was recovered from level 7 in unit N97 E96, and another variant was recovered from level 6 in N99 E97 (Brown 1983:Fig. 16, k, m). Both are near the lower contact for stratum 5. A third specimen (Brown 1983:Fig. 16, l) was found much higher in level 2. Little is known about the age of these artifacts, but Hudler estimates an approximate age of 2800-3100 RCYBP ("Analytical Unit C") at the Smith Creek Bridge site in De Witt County, based on a radiocarbon assay of 2860±40 RCYBP (Hudler, Prilliman and Gustavson 2002:56). Based on these findings, it may be reasonable to estimate that stratum 5 began accumulating about 3000 RCYBP, or approximately at the beginning of the Late Holocene mesic climatic interval.

Estimating the most recent age limit for stratum 5 is more difficult. The creek lies far below the surface of the site now and contributes no sediment to the surface. Any surface accretion occurring now can only come from very minor sheetwash off the gentle slope to the south. When did Coleto Creek stop contributing overbank sediment and incise far enough below the blufftop that even major floods could not overtop the site? The most recent prehistoric artifacts recovered were Perdiz points (levels 1 and 2) and bone-tempered plainware sherds (level 1; Brown 1983:67-69, Fig. 16). Four long bones or fragments from levels 1 and 2 were also identified as bison or cow. These Toyah Phase items probably date about 1250-1700 cal AD (very roughly 795-220 RCYBP). Since they were found shallowly buried, it may perhaps be assumed that sediment deposition ceased sometime around 1250-1700 AD. Alternately, deposition might have ceased somewhat earlier, with the Perdiz points and potsherds discarded on the surface but later buried by

bioturbation. A thin (0-11 cm) zone of culturally sterile sand overlies the midden (Brown 1983:Figs. 5-6, zone 5c), evidently representing either sheetwashed colluvium or overbank sands. A couple of metal artifacts were also recovered from level 1, and these surely must have been buried by disturbance processes.

The Smith Creek Bridge site could be used for comparison (a single Perdiz point and some ceramics were found there) if 10-50 cm of sediment had not been removed from the site before excavations started (Hudler, Prilliman and Gustavson 2002:1). A thick package of sediment has been deposited on the south side of the channel in very recent historic time (Collins 1999), but not on the north side, which is higher. The Burris site (41 VT 66/VT41) is located about 9.7 km downstream from Berger Bluff just across the Victoria County line, and likewise on the southwest bank, on a steep bluff above the channel, here incised about 12 m below the site. The site has a small Toyah Phase midden (Feature 3) with Perdiz points and bison bone at about 20-40 cm below the surface (but some bone as high as 10-20 cm and some as deep as 50-60 cm; Shaffer 1989:173). The depth of burial for the Toyah Phase component is only slightly greater (20 cm) than at Berger Bluff, but there is a fairly steep hillside to the south (Brown 1983:Fig. 20) which might have contributed colluvium. The same question arises here as at Berger Bluff: did the thin veneer of sediment over the Toyah Phase component originate as 1) sheetwashed colluvium (probably the most plausible source), 2) overbank deposition, or 3) eolian deposition (the least likely source, in my view)?

Given the uncertainty about the date of burial of the Toyah Phase components at these sites, it seems entirely plausible that Coleto Creek might started its incisive phase as

early as 1100 AD. Hall (1990) has reviewed Late Holocene alluvial sequences from Oklahoma to Central Texas. He reports that

> Low rates of sediment deposition characterized flood plains of all stream orders in the region from about 2 to 1 ka, resulting in the formation of a soil characterized by a cumulic, organic-rich, over-thickened A horizon. The soil was first studied and dated in the Little Caney River valley, northeastern Oklahoma, and named the Copan Soil…. (Hall 1990:343).

The Copan Soil formed during the Late Holocene mesic interval (the uppermost radiocarbon assays from this soil average about 900-1000 RCYBP), and is buried at many of the sites studied by Hall. At Berger Bluff, however, there is no later sedimentation and the soil is still forming. Stratum 5 is probably equivalent to the upper member of the West Range alluvium at Fort Hood (Nordt 1992:75). Also possibly equivalent is the Asa Soil, another overthickened, organic-rich soil recognized in the Brazos River valley; however, it dates to 1250-500 RCYBP (Waters and Nordt 1995:317).

A dry interval in the Plains starting about 1000 RCYBP (roughly 1100 cal AD) decreased plant cover and increased sheet erosion rates, leading to a widespread pattern of channel trenching (Hall 1990; Blum, Toomey and Valastro 1994:Fig. 11, F; Arbogast and Johnson 1994:Fig. 4). A review by Daniels and Knox (2005:Fig. 6) suggests the most pronounced evidence occurs about 800-1100 RCYBP, peaking at about 900 RCYBP. The same interval, as well as an interval at 500 RCYBP, occurs in the southwestern US (Waters and Haynes 2001:Fig. 4) and in the Pedernales River valley (Blum and Valastro 1989). A similar episode of entrenchment of the Republican River occurs in Nebraska sometime after 1800-1100 RCYBP (Martin 1992). In the southern Colorado Plateau, arroyo cutting occurs at 1200-1400 cal AD (Hereford 2002). At Berger Bluff, Coleto

Creek incised completely through almost 9 m of sediments in just a few centuries. Wolf Creek incised through the same thickness of sediment in central Kansas at the same time (Arbogast and Johnson 1994).

The incisive event identified by Hall corresponds to the Medieval Climatic Anomaly (Bradley, Hughes, and Diaz 2003:405), a period with fairly warm temperatures that persisted until the beginning of the Little Ice Age. Northern hemisphere temperatures peaked at about 1100 and 1175 AD (Jones, Osborn, and Briffa 2001:Fig. 2). In south Texas, Castro and Goblet (2003) estimate a rapid warming of about 3.4° C between 900 and 600 RCYBP, based on noble gas paleothermometry from the Carrizo aquifer. However, this is also a fairly quiescent period in terms of ENSO events. Although the available fossil coral record has gaps, the densest clusters of extreme ENSO events seen in the reconstructed part of the record occur at about 940, 1200, and 1390 AD, and from about 1630 AD to the present (Cobb *et al.* 2003:Fig. 6). It also corresponds to a minimum in magnetic susceptibility values and arboreal pollen at Camp Bullis Bat Cave (Hudler 2000:Figs. 4-15, 4-20) and to the onset of eolian episodes at Lubbock Lake, Marks Beach (Forman, Oglesby, and Webb (2001:Fig. 4) and elsewhere in the Plains (Madole 1994; Mason *et al*. 2004). Salinity records from Plains lakes indicate high frequency of extreme droughts at 1000-1200 AD (Laird *et al*. 1996). Brown *et a*l (1999:507-508) report Midwestern megaflood events in the Orca Basin sedimentary record at about 1200 cal AD (approximately 840 RCYBP, using an assumed marine reservoir age of 400 years).

Biological Clues to Late Prehistoric Hydrology

Curiously, the upper part of stratum 5 contains large numbers of gar elements (mostly ganoid scales, some vertebrae, and a few dentary or mandible fragments, found

in nearly all the units). By far, the largest number occur at 15-30 cm, but a significant number occur at 0-15 cm, and some are found at 30-60 cm. Apparently none were recovered below level 4 (Flynn 1983:Table 23). Some of these are identified as longnosed gar, *Lepisosteus osseus.* Longnosed gar prefer deep pools, oxbows and vegetation-choked backwaters, although they spawn in clear-flowing shallow gravelly riffles in spring. Most of the gar elements are not identified to species, and besides the longnosed gar, spotted gar (*L. oculatus*) and alligator gar (*L. spatula*) also occur in the region. Alligator gar prefers habitat similar to the longnosed gar, but spotted gar prefers clear water.

Regardless of the species involved, significant numbers of gar probably imply the presence of deep pools nearby – perhaps a pool and riffle configuration like that further downstream – unless the fish were taken only during spawning season. Remains of various aquatic turtles were also found in the upper 60 cm of stratum 5 at Berger Bluff. Like the gar, most of the identified specimens were found in level 2 (15-30 cm), with a lesser number in level 1. Most of these were spiny softshell turtle, listed by Flynn as *Trionyx spiniferus.* These may be the Guadalupe spiny softshell, listed as *Trionyx spiniferus guadalupensis* by Garrett and Barker (1987:121-122) and *as Apalone spinifera guadalupensis* by Vermersch (1992:129-131). It prefers "moderate to fast current and sandy or muddy bottoms" Garrett and Barker (1987:121). Red-eared slider *(Trachemys scripta*) was also tentatively identified from carapace fragments (Flynn 1983:105) in levels 1-3 (0-45 cm). This species favors slow-moving waters with soft, muddy bottoms and submergent vegetation (Garrett and Barker (1987:106). River cooter is also reported from level 1 (carapace fragments, listed as *Chrysemys concinna*) in one unit. Presumably this is Texas River Cooter, listed as *Pseudemys texana* by Garrett and Barker (1987:100)

and Vermersch (1992:109-112). It prefers slow-moving water with abundant aquatic vegetation.

Beaver teeth were recovered from the Morhiss component at the Smith Creek Bridge site (Froelich 2002:Table 100) but beaver remains are not known from any of the Berger Bluff deposits or any of the other nearby sites in the lower part of the catchment.

Freshwater mussel shells from the upper 15 cm of stratum 5 include Threeridge (*Amblema plicata*), Texas Pimpleback (*Quadrula petrina*), Southern *Mapleleaf (Q. apiculata*), Tampico Pearlymussel (*Cyrtonaias tampicoensis*), Yellow Sandshell (*Lampsilis teres*), and Texas Lilliput (*Toxolasma texasensis*). Only two of these species were found in the bench deposits. Most of these species tend to occur frequently in muddy bottoms, often with fairly slow flow, and do not tolerate deep, shifting sand, although they can also occur in shallower, faster water. The Threeridge (which is abundant) tolerates drought and low water quality, while the Yellow Sandshell (which is infrequent) is intolerant of drought. The Texas Lilliput is a small pond species, found today in nearby stock ponds on the Beaumont terrace surface. A somewhat larger suite of species was found at the Smith Creek Bridge site (Howells 2002:Table 67), but level 1 at that site contained only the Threeridge (Howells 2002:Table 66) and only a small sample of mussels from stratum 5 at Berger Bluff has been identified.

In general, the freshwater mussel taxonomic composition suggests deep, fairly stable, perhaps mud-bottomed pools, a configuration consistent with the presence of gar, as noted. On the other hand, nearly all the individual shells in the stratum 5 midden are fairly small, young individuals. The same pattern appears at the Smith Creek Bridge site

(Howells 2002: 202). Examination of the one species (the Threeridge) common both to the level 1 sample from stratum 5 and to the bench deposits shows that the stratum 5 individuals are conspicuously smaller than the bench specimens, suggesting either increased collecting pressure or more frequent washouts, preventing the Late Holocene individuals from reaching full adult size. The freshwater mussel evidence will be presented in more detail in a later chapter.

The apparent absence of freshwater sponges during the accumulation of stratum 5 is notable, but the habitat conditions controlling sponge growth are poorly understood. Robinson (1979) reports sponge spicules from all of the samples examined at 41 GD 21, including the one collected at a depth of 10-20 cm. Sponge spicules (megascleres) were absent from all of the stratum 4 and 5 samples examined and collected from the blufftop excavation block, both the two diatom samples analyzed by Barbara Winsborough and the four dry sediment samples that I scanned myself. I found one or two small fragments on an archival duplicate of slide 29 furnished by Winsborough (see Fig. 7.20), but otherwise spicules seem to be absent from this stratum. The spicules are small enough to be wind-deposited and are found in Midwestern loess deposits (Jones and Beavers 1963), so the depositional agent is not an issue. It seems likely that Coleto Creek became unsuitable habitat for sponges by the onset of the Late Holocene. Perhaps base flow rates became too low, or water temperatures too high, or the water was too poorly oxygenated. All of these factors could be present if deep pools isolated by very shallow connecting riffles were present in the Late Holocene. Sponges are filter feeders, so they need at least some water flow. Siltation might affect them adversely, yet Cheatum and Harris (1953:100) found high turbidity had no adverse effects on sponges in the Trinity River – some colonies were living in mud-covered conditions. Most sponges lived in habitats

with turbidity readings ranging from 20 to 150 ppm, but at times, readings went as high as 5300 ppm. Water temperatures above 30° C (86° F) and declining water levels can have adverse effects (Harrison 1974:34). No freshwater sponges were reported from Coleto Creek in the pre-inundation aquatic ecology study by Murray, Jinnette and Moseley (1976).

Another possibility is that diatoms and sponge spicules are simply not well preserved in the upper deposits. Both are silicate forms, however (the spicules are hydrated silica, or opal), and should be chemically similar to the quartz sand enclosing them. Yet another possibility is that all of the sponge spicules in the Berger Bluff deposits are reworked from the lower part of the Lissie terrace deposits upstream, and spicules are absent from stratum 5 and the upper part of stratum 4 simply because the creek channel had become well elevated above that part of the Lissie terrace by then, and had raised itself above the source for reworked spicules. Spicules were found no higher than sample 1-2 in Lissie section 1 (Fig. 4.13).

Late Holocene Environmental Changes: Summary

Near Berger Bluff and upstream throughout most of the catchment, Coleto Creek is wide, shallow, rather deeply entrenched into its valley, and heavily sand choked (before impoundment; see descriptions in Chapter 1). As far as can be determined from historical accounts, this configuration already existed when the earliest European settlers arrived, and it cannot be attributed to historic Euroamerican land modification (see historical review in Chapter 1).

The aquatic animal remains recovered from the upper deposits allow us to guess at hydrological conditions in the creek during the Late Holocene (from about 3000 RCYBP to perhaps 795-220 RCYBP). The available evidence seems to indicate the creek looked rather different then, and hints at the presence of some fairly deep, large pools nearby, perhaps with rather sluggish flow conditions. Neither the gar nor the various kinds of freshwater mussels are found very near the site today (yellow catfish and buffalo were the largest fish found in this reach of the creek before impoundment).

From the respectable thickness of strata 4 and 5, it is clear that massive amounts of sand were transported through the Coleto Creek drainage during the Holocene, with part of the sand lodged in temporary storage throughout the valley. By the Late Holocene, the channel base was evidently well elevated above its present position and then, sometime in the Late Holocene, the channel began rapidly incising downward toward its contemporary position. The trigger for entrenchment might have a regional arid phase like that identified at 1000 RCYBP by Hall (1990), but there have been several arid episodes in the Late Holocene, some later than that singled out by Hall. Holliday (2001), for example, recognizes arid phases at 1150-1650 RCYBP, 800 RCYBP, and 300-450 RCYBP on the southern High Plains.

Another possible geomorphic event trigger might have been increasing stream gradient caused by falling sea level. There is fairly good evidence that sea level in the Gulf had risen to a highstand of nearly 3 m above present levels by the Late Holocene, roughly 1500-2500 RCYBP (Kibler 1994:56; Walker, Stapor and Marquardt 1995; Morton, Paine and Blum 2000; Blum *et al*. 2002), then falling to present levels shortly after 1000 RCYBP. A steadily falling sea level after 1500 RCYBP, coinciding with a

regional arid phase at 1150-1650 RCYBP might have crossed a geomorphic threshold that triggered the regional stream entrenchment that is still ongoing in Texas rivers and creeks today. In addition to base level reduction and increased frequency and severity of flash flooding, other factors such as reduction in sediment load (or change in channel morphology (sinuosity or width-depth ratio) can trigger stream incision.

In any case, entrenchment and evolution of the creek to its present sand-choked state evidently occurred sometime in the Late Holocene, but without better chronological control, we cannot say whether the process began during the Toyah Phase or earlier. Even if entrenchment began as early as 1100 RCYBP, the creek might have continued to overtop the terrace and add some sediment for some centuries afterward.

Once incision began, it evidently proceeded rapidly. Hereford (1984:665) points out that incised channels tend to focus flood energy and prevent floods from spreading out and dissipating their erosive force. Incision therefore acts as a positive feedback process, once the erosive threshold is crossed.

DEPOSITIONAL PROPERTIES OF THE BENCH SEDIMENTS

Sediment Texture

Laboratory methods and data for grain-size analysis are documented in Appendix 1. The bench sediments in general consist of roughly equal amounts of sand, silt, and clay (gravel is scarce except for stratum 2E and certain levels in stratum 1), but the proportions vary significantly by stratum (Fig. 4.65). The bench alluvium is made up of alternating sandy and muddy strata, and these can tentatively be arranged in pairs or couplets:

Stratum 3: muddy, thick
Stratum 2D: sandy, thick, fining upwards

Stratum 2C: muddy, thin, coarsening upwards, not prominent
Stratum 2B: sandy, thin

Stratum 2A: muddy, thick
Stratum 1: sandy, thick, fining upwards

The thickness relationships are perhaps best seen in Fig. 4.23. Textural relationships are plotted in a variety of ways in Fig. 4.66 through Fig. 4.72. The basic data for these illustrations come from the composite grain-size column consisting of 25 samples at 5 cm intervals from N110 E102, plus three more samples from N109 E103 added at the top of the column. Fig. 4.67 adds some additional samples from N109 E96, stratum 2E, the upper deposits, and Coleto Creek. Figs. 4.66 and 4.68 also include one sample from stratum 2E.

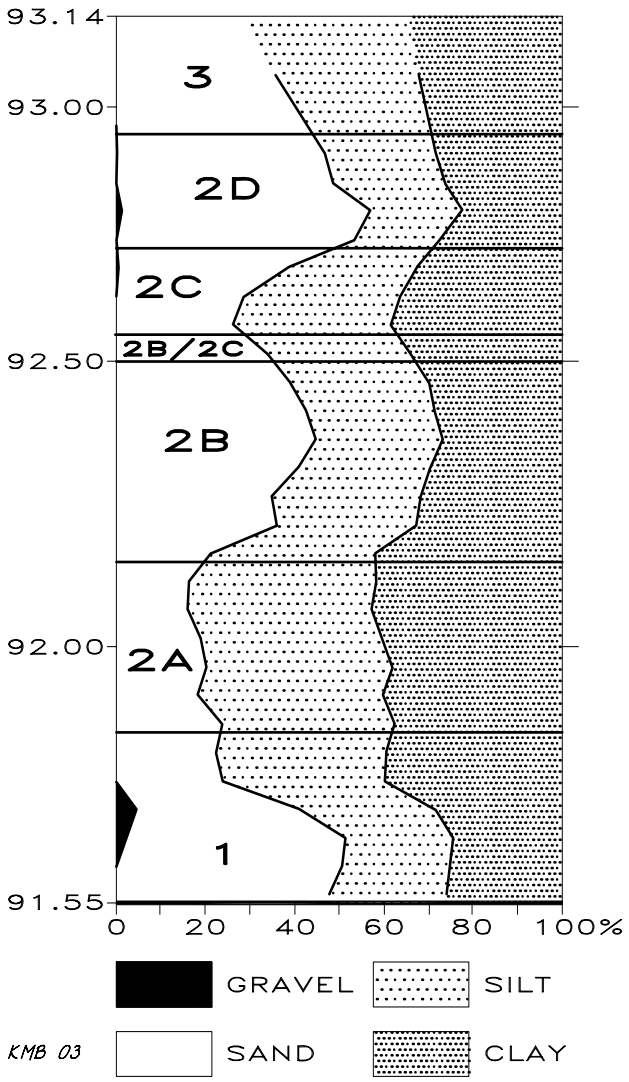
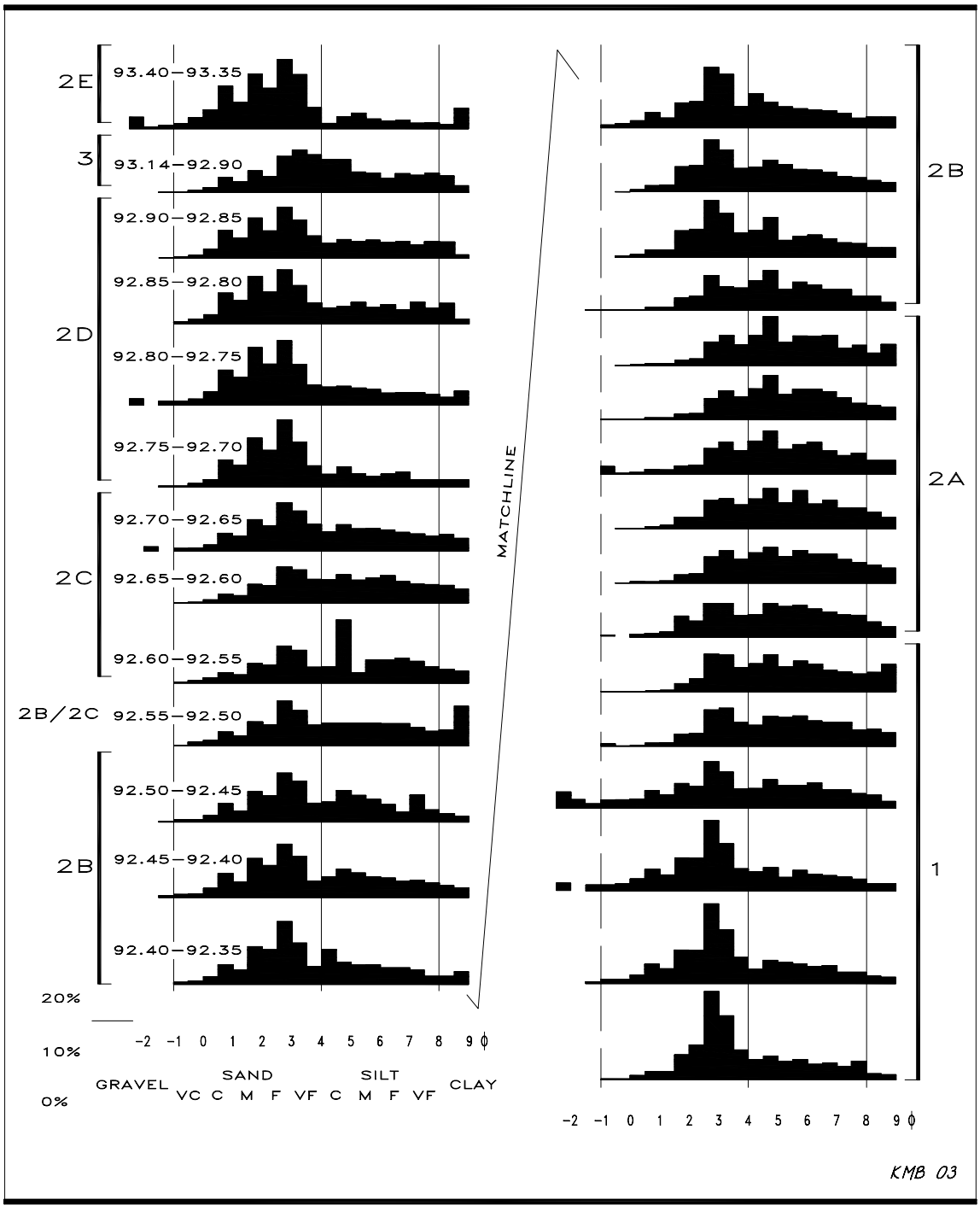


Figure 4.65. Stratigraphic Distribution of Gravel, Sand, Silt and Clay**.** Level-by-level distribution of gravel, sand, silt, and clay. The uppermost data point is for a single sample extracted from stratum 2E in the cutbank (see Fig. 3.1 for location). The next three data points (extending from 93.14 to 92.80 m) come from the southwest corner of unit N109 E103, and the remaining 25 data points are from the southwest corner of N110 E102. Stratum boundaries are shown by heavy horizontal lines. Clay percentages are for total clay (not just the two analyzed grades) plus analytical error.

Figure 4.66. Grain-Size Sample Column: Stacked Histograms (*following page)*. Level-by-level distribution of grain size, in half-hi increments from –2.5 phi to +9.0 phi, in order by elevation and stratigraphy. The uppermost histogram is for a single sample extracted from stratum 2E in the cutbank (see Fig. 3.1 for location). Four samples were collected, but only one (which cut into a lens of pea gravel) was analyzed. The next three samples (extending from 93.14 to 92.80 m) come from the southwest corner of unit N109 E103, and the remaining samples are from the southwest corner of N110 E102. The brackets on left and right indicate stratigraphic assignments, and the vertical lines are the major divisions for gravel, sand, silt, and clay. Note that only the two coarsest grades of clay were analyzed; there is an infinite tail of unanalyzed clay grades on the right side of each histogram. The key shows the Wentworth classification (VC = very coarse, C = coarse, M = medium, F = fine, VF = very fine) and the vertical scale, the height of each histogram bar in terms of percentage of sample. Note the persistence of modes from level to level, the conspicuous skewness of most histograms, and the varying amounts of silt in the sample.


2E
93.40–93.35
3
93.14–92.90
2D
92.90–92.85
92.85–92.80
92.80–92.75
92.75–92.70
2C
92.70–92.65
92.65–92.60
92.60–92.55
2B/2C
92.55–92.50
2B
92.50–92.45
92.45–92.40
92.40–92.35
MATCHLINE
2B
2A
1
20%
10%
0%
−2 −1 0 1 2 3 4 5 6 7 8 9 ϕ
GRAVEL
SAND
SILT
CLAY
VC C M F VF C M F VF
KMB 03

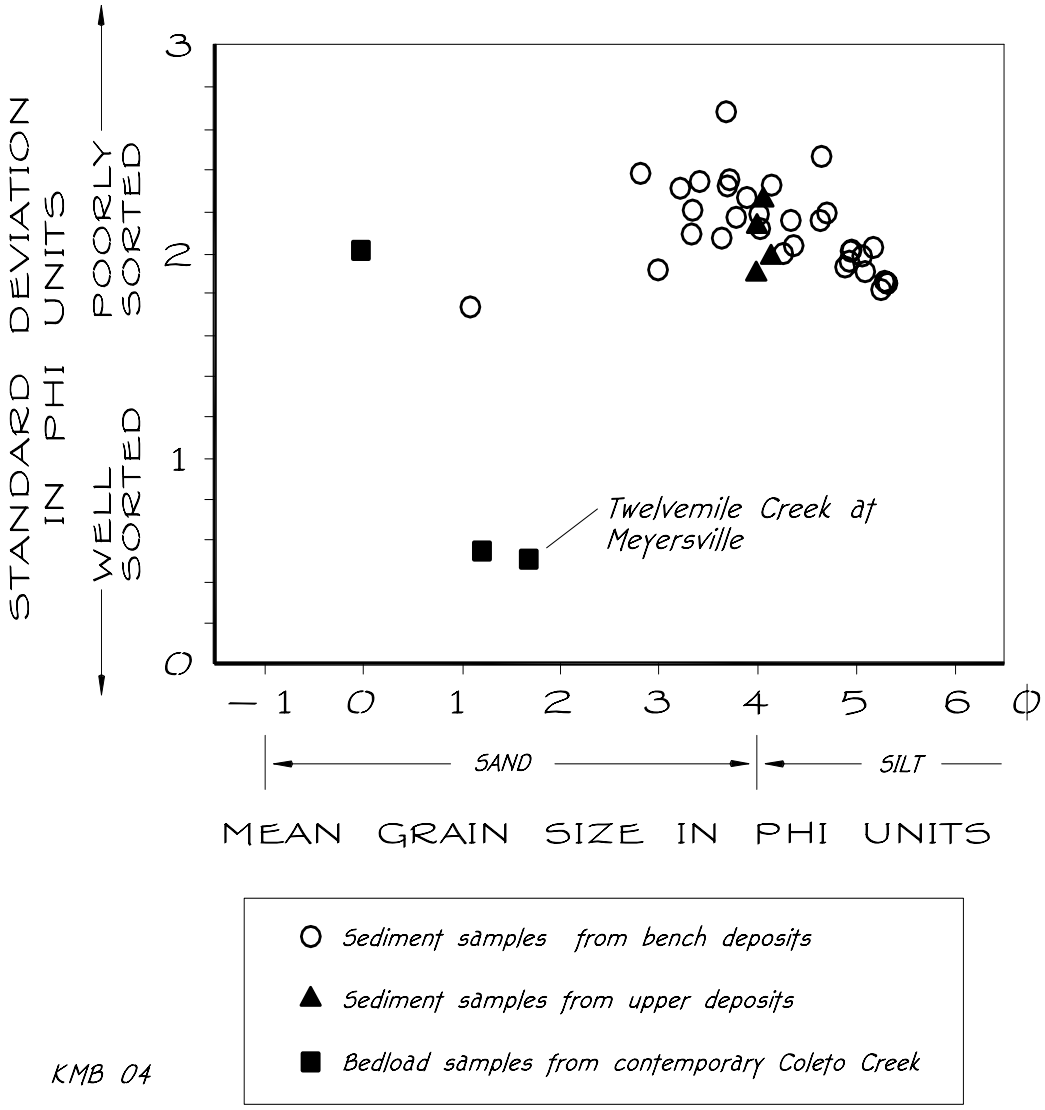


Figure 4.67. Berger Bluff and Coleto Creek Bedload Samples: Scattergram of Mean Grain Size Versus Standard Deviation. Plotted here are three contemporary bedload samples from Coleto Creek, 33 samples from the bench deposits, and four samples from the upper deposits. The coarsest bench sample (single isolated open circle at left side of scatter) is a sample of gravel and sand only from stratum 2E (93.45-93.40 m). Fines were not analyzed for that sample, but are believed to be insignificant in proportion. The stratum 2E samples may represent displaced bedload material.

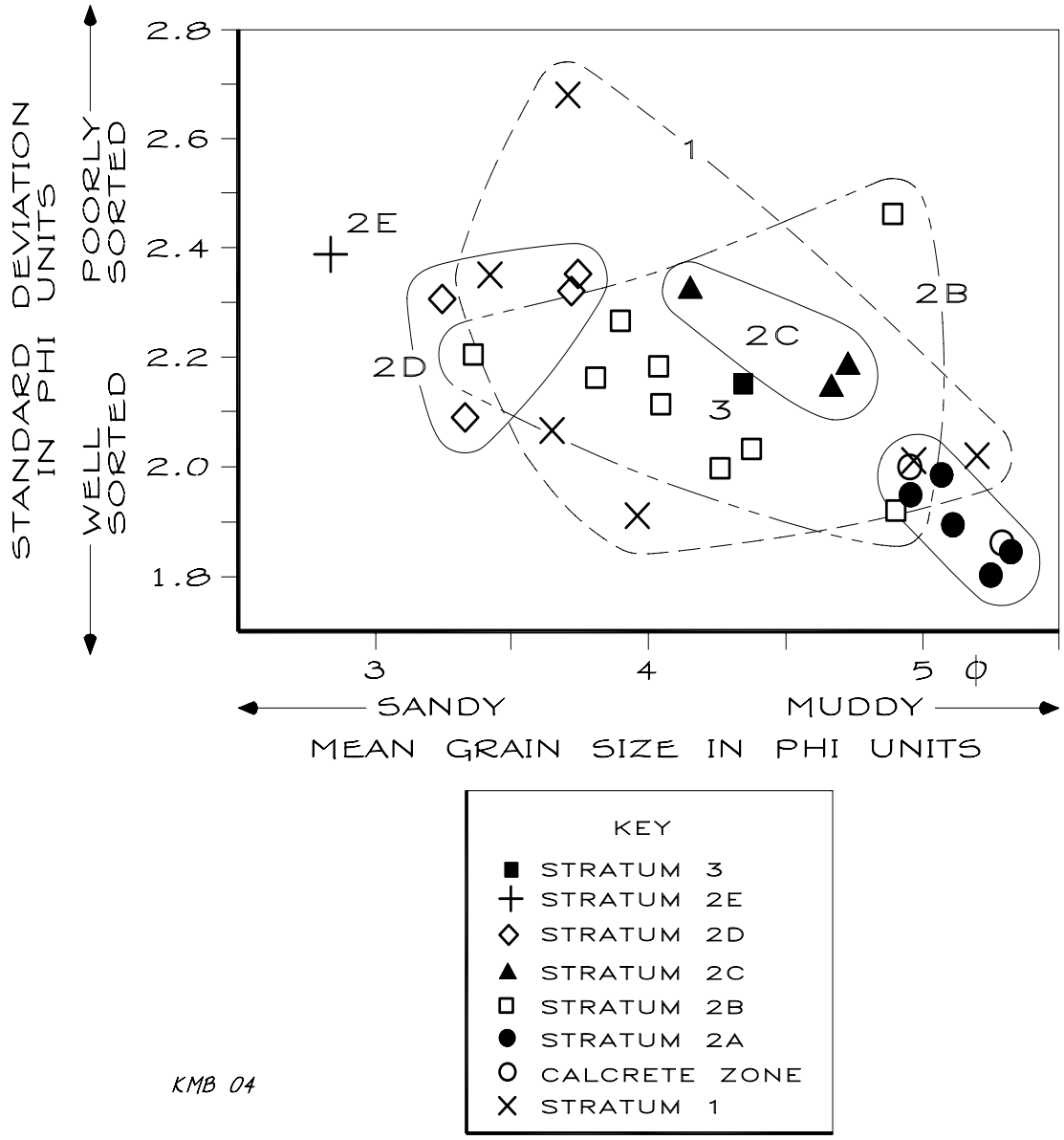


Figure 4.68. Grain-Size Sample Column: Scattergram of Mean Grain Size Versus Standard Deviation. Plotted here are three samples from N109 E103, 25 from N110 E102, two from N109 E96, and a single sample from stratum 2E collected from the cutbank. Mean grain size (a measure of texture) is plotted against the standard deviation of the grain size (a measure of sorting), both expressed in phi units. This graph shows that each stratum has a distinctive textural signature, and that the sandy units ("open" symbols) are much more variable than the muddy units (filled circles, triangles, and square), but they become less variable over time (the scatter of points from strata 1, 2B, and 2D becomes progressively smaller).

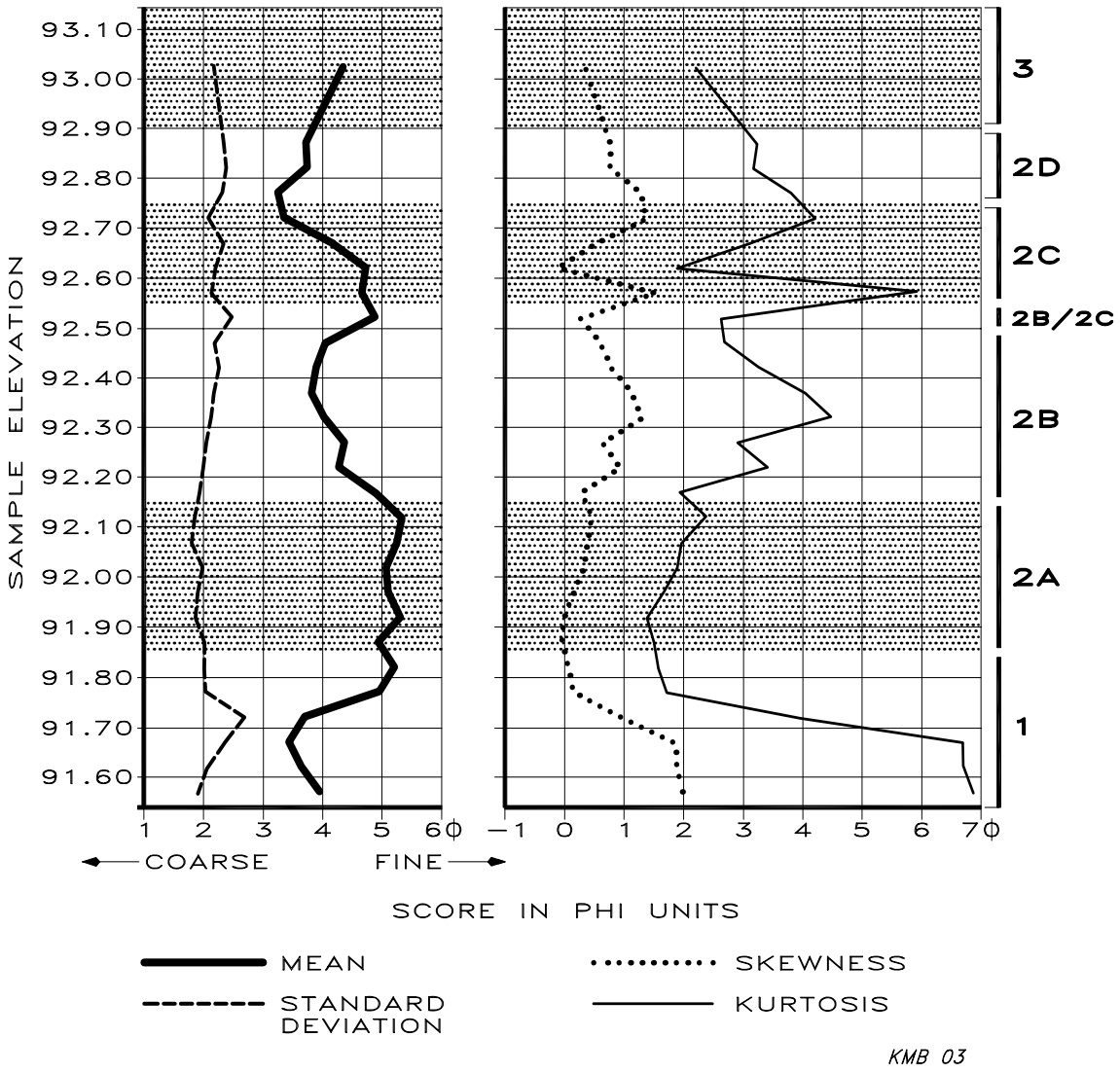


Figure 4.69. Grain-Size Sample Column: Stratigraphic Plot of Statistics. Mean, standard deviation, skewness, and kurtosis in phi units are plotted for all grades (including only the two coarsest grades of clay, however). The uppermost three data points come from N109 E103, and the remaining 25 data points are from the N110 E102 sample column. Elevation (93.14 m to 91.55 m) is shown on the left, and stratigraphic divisions are shown on the right. Note that this plot does not include the stratum 2E sample collected from the cutbank.

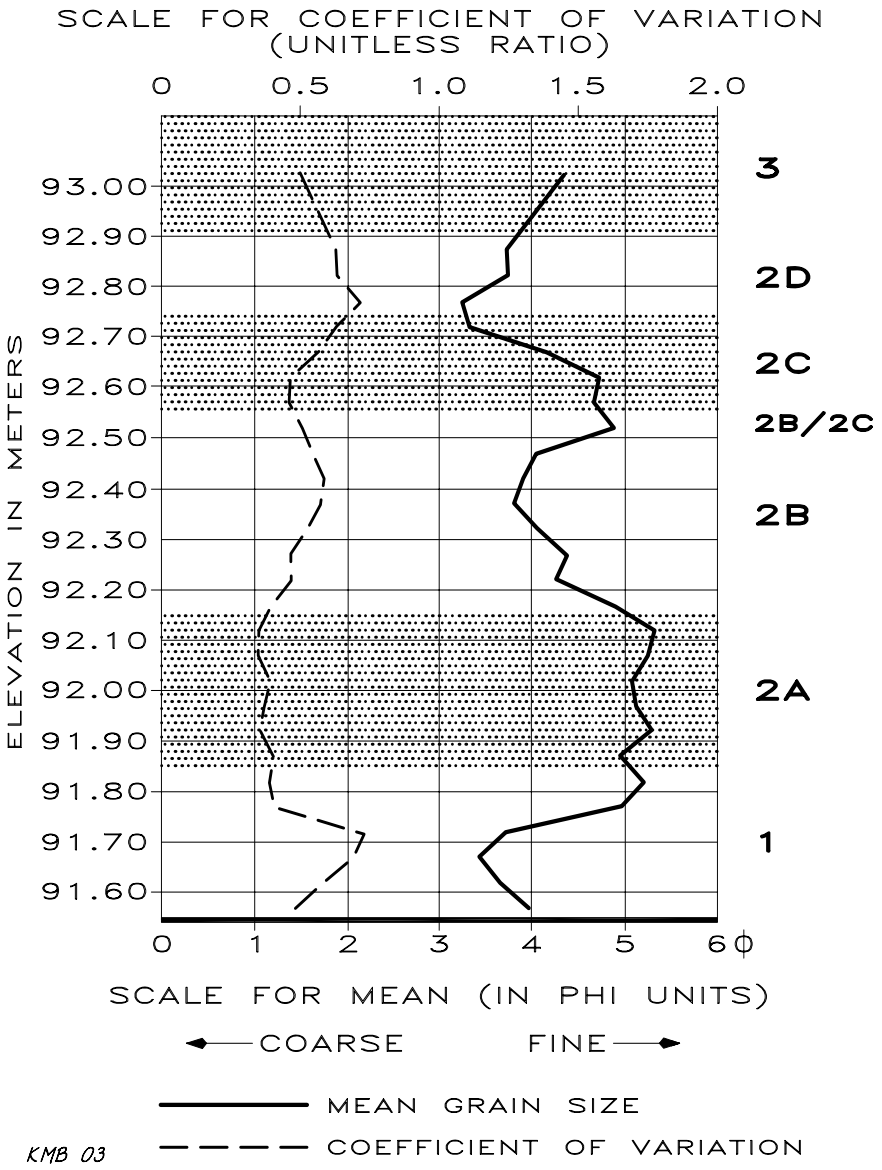


Figure 4.70. Grain-Size Sample Column: Stratigraphic Plot of Grain-Size Mean and Coefficient of Variation. This double-axis plot shows that texture and sorting are interrelated, even when sorting is expressed by the coefficient of variation rather than the standard deviation.). The uppermost three data points come from N109 E103, and the remaining 25 data points are from the N110 E102 sample column. Elevation (93.14 m to 91.55 m) is shown on the left. Note that this plot does not include the stratum 2E sample collected from the cutbank.

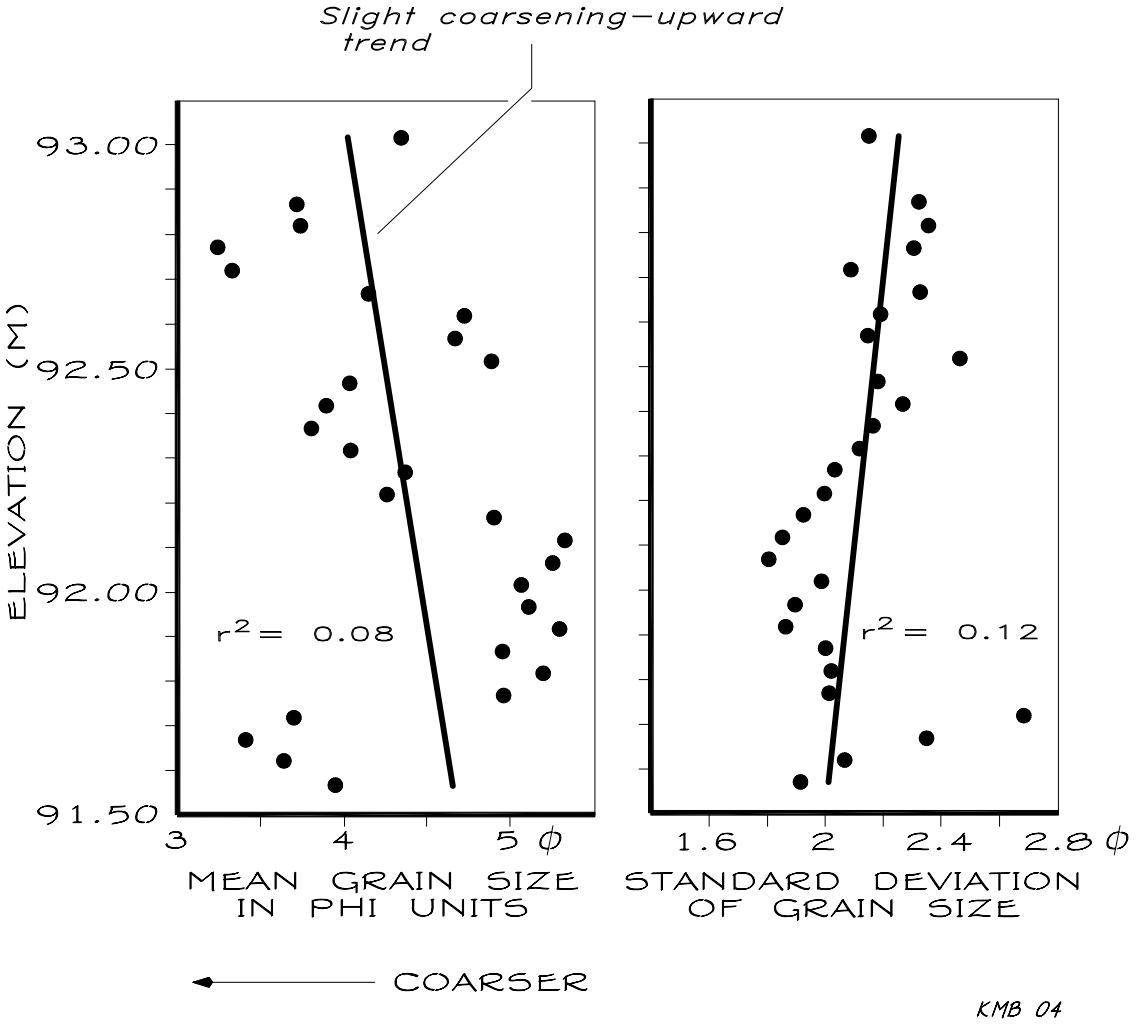


Figure 4.71. Bench Deposits: Grain Size Regressed Against Elevation. Regression lines are fitted to mean and standard deviation of grain size (in phi units) for the sample column from the bench. Short-term variation about the regression line is much more significant than any long-term trends shown by the lines (note very low r^2 values). The sediments show a very slight coarsening-upward trend.

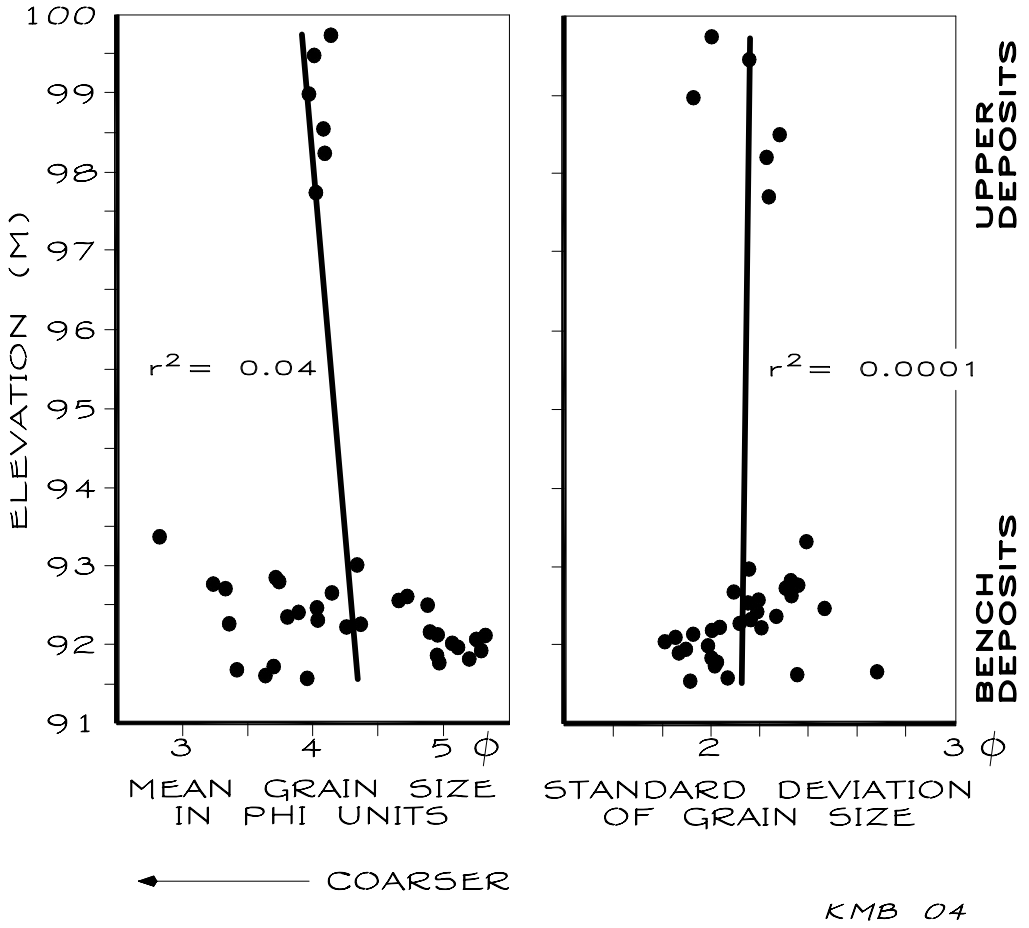


Figure 4.72. Bench and Upper Deposits: Grain Size Regressed Against Elevation. In this plot, elevation is rescaled from the previous figure and six samples from the upper deposits (strata 4 and 5) are added (no data are available from the middle part of the stratigraphic section). These plots demonstrate even more dramatically that there is little or no long-term trend in grain-size variation, and that short-term variation occurs on a much larger scale. Note also how much more variable the bench samples are than the upper samples.

Most textural properties show inflection points (indicating some kind of trend that reverses) close to stratum boundaries as drawn on the unit profiles (see, for example, Fig. 4.65 and Fig. 4.69), but the inflection points do not coincide exactly, because the contacts seen in the unit walls were generally vague and gradational, most likely because limited postdepositional bioturbation has smeared the boundaries.

Many floodplain or stream terrace deposits are characterized by "fining-upwards" sediment texture – that is, the higher in the stratigraphic sequence, the finer-grained the sediment becomes (Waters 1992:132-135). Where floodplains are built *by lateral accretion*, the material making up the floodplain is stratified by weight and size. The coarse-grained gravel making up the traction load stays near the base of the channel, coarse sand is deposited at the bases of point bars, finer sand is deposited on the top parts of point bars, and fine-grained sands and silts from the suspended load are deposited on top as a "topstratum" deposit.

Even if the floodplain is chiefly built up by *vertical accretion*, the sediments may still show a fining-upward pattern. If the channel bed is stable or slowly incising while the floodplain surface is built up by overbank deposition, the surface becomes higher and higher through time, and it becomes more and more difficult for floodwaters to overtop the channel banks and cover the floodplain. As the surface rises, only the upper part of the water column can spread over the floodplain, and it is the upper part of the water column that carries the finest sediment. As a result, both the rate of deposition (Wolman and Leopold 1957:Fig. 64; Hereford 1984; Moody, Pizzuto, and Meade 1999:301, Fig. 7; Moody and Troutman 2000:120) and perhaps the grain size of the overbank sediment will diminish through time.

Taken as a whole, the bench deposits as a whole display no upward fining. Figures 4.65 and 4.69 show that, while there is significant stratum-by-stratum variation, there are no pronounced long-term trends. If a regression line is fitted to the data points for mean grain size in Fig. 4.69, there is actually a very slight ($r^2 = 0.08$) trend toward upward coarsening (shown as Fig. 4.71). Grain size can be expressed as

$$y = -0.4332 x + 44.319$$

where y = mean grain size per sample in phi units
x = elevation in meters

The lack of upward fining is probably due to the fact that the bench deposits are chiefly overbank vertical accretion deposits with an exceedingly slow accretion rate. All the deposits are fairly fine-grained to begin with, and accumulation rates were so low that terrace height never became a significant factor conditioning deposition, at least not in this early part of the site's history. The slight trend toward upward coarsening might be an expression of long-term climatic processes during the Younger Dryas. A regression line fitted to the data points for the standard deviation of grain size indicates a slight ($r^2 = 0.12$) trend toward larger standard deviations up-section (Fig. 4.71, right panel).

If the regression is extended to include the grain size samples from the upper deposits, the same trends are found, but are even less pronounced. Mean grain size coarsens slightly ($r^2 = 0.04$), but there is almost no vertical trend for standard deviation of grain size ($r^2 = 0.0001$, Fig. 4.72). Clearly, short-term variation is much more dramatic than any long-term variation in grain size expressed throughout the Holocene.

Sediment texture is the sum of two components: an *inherited texture* component and a *depositional process* component. Grain size can be analyzed both by looking at summary statistics (mean, standard deviation, skewness and kurtosis) and at patterns of individual sand or silt modes (the peaks that appear in histograms like Fig. 4.66). Some of the modal properties of the sediment may be inherited from the original Miocene source sediment. Most of the Goliad sandstone (Fig. 4.9), Coleto Creek bedload (Fig. 1.48), and lower post-Beaumont surface samples (Fig. 4.7) have sand modes that are somewhat coarser than those found in the bench sediments, but there are some points of coincidence.

Figure 4.66 is a reasonably complete textural cross-section of the excavated sample of the bench deposits. It can be read by starting at the bottom righthand corner, working upward, and then visually stacking the lefthand column on top of the right column. The most conspicuous mode is one for fine and very fine sand, at 2.5 to 3.5 Φ, running through all the samples. This mode also appears in the lower two Goliad sandstone samples shown in Fig. 4.9, and it may be that the dominance of this particular grade of sediment is partly inherited from Miocene source sediments, and partly the result of depositional processes. Sediment of this size is usually found as coarse suspension load, near the textural boundary between bedload and suspended load. Sand from the contemporary creek bed (Fig. 1.48, various modes mostly from 0.5 to 2.0 Φ, as well as gravel) and the terrace surface on the Preiss Ranch (Fig. 4.7, mode at 1.5 to 2.0 Φ) are mostly in the coarse to medium sand range. The former is coarser by virtue of being bedload, not overbank material, but the latter undoubtedly registers the higher fluvial energy levels seen in the Holocene. Figure 4.67 shows how the overbank sediment samples from the bench and the upper deposits compare with bedload samples from

contemporary Coleto Creek. The isolated bench sample (a single circle toward the left side of Fig. 4.67) is from stratum 2E in the cutbank. As the plot indicates, the bedload samples are markedly coarser, and two of the three are much better sorted than the Berger Bluff samples.

Other less conspicuous modes that can be picked out from the histograms in Fig. 4.66 include a coarse silt mode (4.5 to 5.0 Φ) that begins in the upper part of stratum 1 and runs through stratum 2C, and two secondary and tertiary sand modes that begin in stratum 2C and run to the top of the column. One is for medium sand (1.5 to 3.0 Φ) and one for coarse sand (0.5 to 1.0 Φ). These represent the coarsening-upward trend that appears above 92.65 m, but notice also that silt and clay are also significantly diminished above 92.65 m. This indicates not just the addition of coarser grades of sand, but the reduction of suspended load, probably because of shortening of flood duration.

The small number of samples with pulses of gravel can also be picked out from Fig. 4.66 – these appear as isolated blocks on the far left end of the histogram at 91.75 to 91.65, 92.70-92.65, 92.80-92.75, and 93.40-93.35. These may be the residue from individual more substantial floods. The sample at 92.05-92.00 is anomalous, because the sediment at this level is otherwise very fine-grained.

The lowest three samples in the column (91.70 to 91.55 m) have very peaked sand fractions and relatively little silt or clay, indicating comparatively high-energy deposition. The fourth sample from the base (91.75-91.70) is very heterogeneous. It has significant amounts of gravel, but also an increase in fines. Above this sample, the next nine samples (92.20 to 91.75 m), drawn from stratum 2A and the calcrete zone at the top of stratum 1,

have increased quantities of silt and clay and much less sand, suggesting a significant increase in flood duration. In the next seven samples (92.60-92.20 m), the sand returns and the fines diminish. in stratum 2B. In stratum 2C (92.70-92.55 m), the proportions reverse again. Silt and clay increases somewhat, but increasing quantities of sand appear in the upper two samples. Above 92.65 m, polymodal sand fractions appear (especially in stratum 2E). The source of this polymodality is uncertain, but it is clear that the *competence* (sediment-carrying ability) of the creek has increased above the 92.65 m level.

In Fig. 4.68, the bench samples plotted in Fig. 4.67 are shown in greater detail (the isolated stratum 2E sampled is omitted here for scaling purposes). Although the bench strata can be grouped into "sandy" or "muddy" end members, each stratum has a fairly unique grain-size signature when mean grain size is plotted against sorting. The scattergram shows that the sandy units (open symbols) are much more variable than the muddy units (filled symbols), but they become less heterogeneous over time (from stratum 1 to 2B, to 2D, the spread of points becomes smaller, and there is a long-term trend toward coarser grain size and more heterogeneous (less well sorted) texture. The general trend of the samples up-section is to progress from the lower right to the upper left part of Fig. 4.68.

Figure 4.69 shows the mean, standard deviation, skewness, and kurtosis of samples in the grain-size data column for the bench samples. Because the standard deviation is partly dependent on the size of the mean, it is not a truly independent statistic. In Fig. 4.70, I have replotted the mean, and I have weighted the standard deviation by the mean to calculate the *coefficient of variation*, a size-independent

measure of the textural heterogeneity of the sample. The scale for the mean is shown in phi units at the base of the graph, and the scale for the coefficient of variation (a unitless ratio) is shown at the top. The figure shows that even when the effect of textural grade is removed, the vertical trends in sorting remain. There are peaks in sediment heterogeneity near the top of stratum 1, the midpoint of stratum 2B, and at the base of stratum 2D.

Magnetic Susceptibility

Laboratory methods and numerical data for magnetic susceptibility analysis are documented in Appendix 3. Plots for individual excavation units are shown in Figure 4.25, 4.27, 4.31, 4.35, 4.40 and 4.73. Table 4.9 shows magnetic susceptibility values averaged by stratum. Chi values are quite low; low-frequency values for the bench sediments range from a minimum of 2.3332 to a maximum of 7.1828. How do these values compare to other Texas sites?

Table 4.10 shows some comparative susceptibility data for recent archeological projects elsewhere in Texas. I have cited only studies that use cgs units, and most of the values were estimated from published stratigraphic plots, since the actual numbers are rarely given in the publications. Studies that use field measuring devices usually employ SI units, and these are not consulted here. The table shows that the Berger Bluff susceptibility readings are comparable to most of those from sandy sediments in the eastern part of the state, except for 41 LE 120, which has unusually high readings. On the other hand maximum susceptibility readings from sites in or near the limestone-derived sediments of the Edwards Plateau are much higher, perhaps because of higher clay content, lower accretion rates than in the East Texas examples, or more concentrated anthrosols.

Table 4.9. Average Magnetic Susceptibility Values by Stratum.

Stratum	Average low frequency chi value	Average high frequency chi value	Average Xfd value	Number of samples averaged
Upper deposits				
5	7.5316	7.0250	4.7619	4
4 (upper part)	4.4352	3.8861	12.3160	6
Bench deposits				
3	no data	no data	no data	none
2E	3.5646	3.1491	12.0319	4
2D	5.0324	4.3830	7.6074	20
2C	5.5721	4.8237	15.6506	11
2B	5.4315	4.9943	8.0037	27
2A	5.9423	4.8345	18.7945	20
1	4.7219	4.5332	4.5751	12

In general, the sandy Miocene sediments in the Berger Bluff catchment do not have a particularly high iron content, compared to bedrock geology in East Texas., although strongly rubified Lissie Formation sediments are present just upstream from the site. The Goliad Formation contains some titanomagnetite (Arredondo and Thomann 1996:287).

Table 4.10. Magnetic Susceptibility Values from Some Texas Archeological Sites.

Site and context	County	Minimum chi value	Maximum chi value	Reference	Fig. or page
Tertiary sand belt					
Valley Branch	Montague				
non-feature		4.45	6.27	Gose (1994a)	334
non-feature		4.04	6.09		333
non-feature		1.13	6.49		332
Feature 3		5.19	6.68		332
Feature 4		5.86	6.48		333
41 LE 120	Lee				
Trench 1		5	>40	Rogers (1997)	Fig. 16
Trench 6		5	22		
Trench 7		14	32		
Trench 8		15	110		Fig. 17
Trench 8		12	36		
Trench 8		7	12		
41 GM 224	Grimes				
Profile 224		3	5	Gose (1994b)	Fig. A-6
Profile A		1	8+		
Profile B		1	8+		
41 GM 166	Grimes				
Location 1		5.2	6.5	Gose (1995)	Fig. 4
Location 2		5.2	6.8		
41 GM 281	Grimes				
Unit 59S		4.2	6.8	Gose (1995)	Fig. 9
Unit 89E		4.2	5.3		
Location A		5	6		Fig. 11
Location B		4	6.2		
Location C		3.8	5		
Location D		3.2	6.8		
Llano Uplift margin					
41 BT 37	Burnet	22.5	35	Gose (2004)	Fig. 1
Edwards Plateau or plateau margin					
Cibolo Crossing	Bexar				
Center block		18	44	Kibler and Scott (2000)	Fig. 11
Culebra Creek	Bexar				
Profile 1		30	68	Gose and Nickels (1998)	Fig 11-9
Profile 2		18	47		Fig 11-8
Profile 3		10	13		
Profile 4		12	14		
Wilson-Leonard	Williamson				
Square 12		0.5	45.5	Takac and Gose (1998)	Tbl 28-2
Square 20		1.8	57.8		Tbl 28-3
Square 33/56		3.9	62.6		Tbl 28-4
Square E28/S78		1.3	45.6		Tbl 28-5
Armstrong	Caldwell				
BHT 5		2	50	Gose (2002)	Fig. 1
Column A		21	70		Fig. 2
Column F		21	77		Fig. 3

Magnetic susceptibility of sediments can be enhanced by pedogenesis, by burning, possibly by human introduction of organic matter, and by alluvial deposition of ferrimagnets. The pattern of susceptibility readings in the upper deposits, in which the chi value (both low and high-frequency) increases significantly above 98. 55 m, suggests enhancement is due to the well-developed, overthickened Late Holocene soil developed here (Fig. 4.74). There could be some cultural contribution, as well, although the maximum low-frequency chi value is only 8.8536. The pattern is similar in shape and scale to profiles from the Valley Branch site (Gose 1994a:332, 333) and 41 GM 224 (Gose 1994b:Fig. A-6, Profile B), and is similar in shape, if not scale, to profiles from the Armstrong site (Gose 2002:Fig. 1). It is also similar to profiles shown by Maher (1998:Fig. 7) and Maher and Taylor (1988:Fig. 2). According to Maher,

> Pedogenic formation of ferrimagnets appears to be favoured in well drained, not very acidic soils (pH ~5.5-7), on weatherable, Fe-bearing (but often *not* Fe-rich) substrates. The amount of magnetic enhancement often shows little correlation with other soil parameters, with the exception of some positive correlation with soil organic carbon… (Maher 1998:47).

Magnetic susceptibility in strata 4 and 5 seems to be controlled largely by pedogenic maturity of the sediments. A different pattern is shown by the susceptibility values from the bench deposits. The values here are only slightly lower than those from the upper deposits, but they tend to oscillate about a central value, without any significant long-term trends. This kind of patterning can also be seen at 41 GM 281 (Gose 1995:Fig. 11, Location A, C) at 41 GM 224 (Gose 1995:Fig. A-6, Profile 224), at the Valley Branch site (Gose 1994a:335), and at the Culebra Creek site (Gose and Nickels 1998:Fig. 11-8, Profile 3, 4). Magnetic enhancement of the bench sediments by organic matter or burning can be ruled out. Organic content is very low, and although there is scattered evidence (in the form of fired clay nodules, heat-fractured chert, and charcoal flecks) of burning, it is

dispersed except for Feature 5 and a possible hearth near unit N109 E96. The two samples that are spatially closest to known or possible firing events are sample 84 (N113 E98, 92.40-92.30 m) and sample 133 (N109 E96, 92.85-92.80 m), and neither has especially high chi values (Appendix 3). Sample 84 is, however, marked by a very low coefficient of frequency dependency, and sample 133 is underlain by two samples with very low coefficients.

Figure 4.73 shows that susceptibility variation in the bench deposits is largely controlled by clay and silt content of the samples. In this figure, I have plotted four variables: 1) low-frequency susceptibility, 2) coefficient of frequency dependency, 3) percentage of carbonate-free sediment represented by silt, and 4) percentage of carbonate-free sediment represented by clay. Since these variables have widely differing values, I have plotted all four as departures from their respective means, in order to get them all on a comparable scale. As the plot shows, all four variables track each other closely through vertical space. Table 4.9 indicates that the average low-frequency low-frequency chi values are slightly higher for the muddy units (strata 2A and 2C) than for the sandy units (1, 2B, 2D, and 2E). The coefficient of frequency dependency is also markedly higher for strata 2A and 2C (although it is also unexpectedly high for stratum 2E).

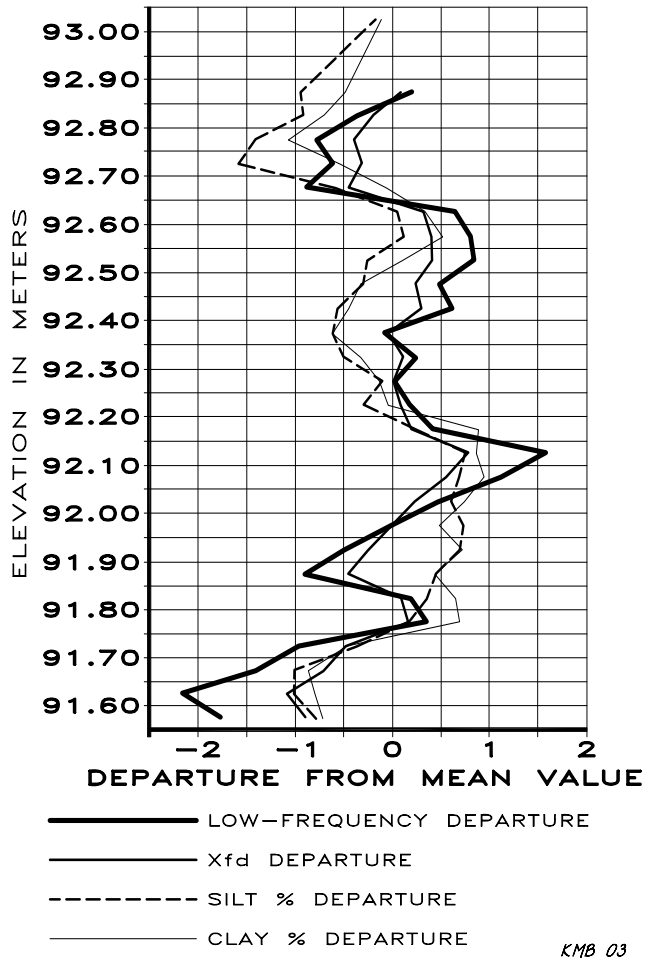


Figure 4.73. Silt, Clay, and Magnetic Susceptibility Curves for Grain-Size Column. All of the values shown here are plotted as departures (either positive or negative) from their mean values, in order to show them all on a comparable scale. The curves differ in length because no phytopol sample was available for magnetic susceptibility subsampling in the uppermost level. The uppermost two silt and clay data points come from the N109 E103 matrix column; the third silt and clay data point also comes from the N109 E103 column. The uppermost magnetic susceptibility data point comes from the upper half of the 92.90-92.80 m level in N110 E102, and the one below that comes from the lower half of the same level. All other data points below that come from the N110 E102 matrix column, at 5 cm intervals. Plotted vertically here are the low-frequency magnetic susceptibility chi value, the coefficient of frequency dependency (Xfd), the percentage of silt, and the percentage of clay in the sample (all as departures from their respective means). The plot shows that all of the curves are highly correlated, and the percentage of fines in the sample appears to control the strength of the magnetic susceptibility signal.

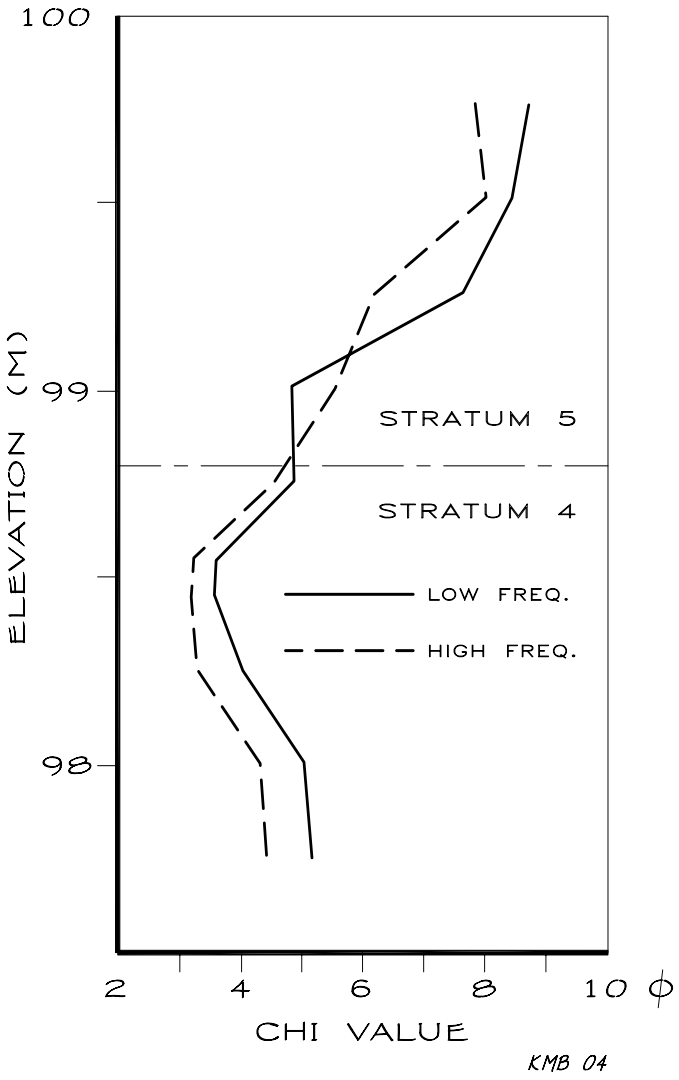


Figure 4.74. Magnetic Susceptibility Curves for the Upper Deposits. Low-frequency and high-frequency chi values are plotted for stratum 4 (six samples) and stratum 5 (four samples). The marked increase in chi values above 98.55 m is due to the presence of the well-developed Late Holocene soil in stratum 5.

Various empirical studies have repeatedly shown that enhanced magnetic susceptibility is associated with finer-grained sediments, chiefly clay particles and to a lesser extent, silt particles (Gale and Hoare 1991:205). A study by Zheng and others of grain-size fractions ranging from fine sand (3Φ) to fine clay (above 10 Φ) shows that susceptibility increases progressively with finer grain size (Zheng *et al*. 1991:Fig. 1). Another study by Feng and Johnson (1995:Table 1) shows the same thing – silt has greater susceptibility than sand, and clay has more than silt. Studies of Holocene Mississippi River floodplain soils show that Fe_2O_3 content is strongly correlated with clay content (Aslan and Autin 1998:Fig. 9, B). The chief conclusion to be drawn is that for the bench sediments, magnetic susceptibility is not a proxy for weathering intensity, but rather a proxy for clay and silt content, and by extension, for overbank flood duration. Its principal value is to provide an indication of the distribution of suspended load in excavation units where no grain-size analysis was done. Quartz sand mostly serves to dilute the magnetic signal, which is probably why most of the sites in the Tertiary sand belt have low chi values similar to those at Berger Bluff. The Cibolo Crossing site furnishes another good example – even though the absolute susceptibility values are higher, here too the values appear to be controlled largely by the relative proportions of sand and clay (see Kibler and Scott 2000:Fig. 11). At Berger Bluff, low values in strata 4 and 5 are probably due both to sand dilution and the relative youthfulness of the blufftop soil horizon.

In the bench deposits, generally speaking, the low-frequency readings spike positively in the two muddy units, strata 2A and 2C, and would probably spike in stratum 3 as well, if more samples were available. The high-frequency readings follow the same trend as the low-frequency readings, but deviate somewhat in some places. Moreover,

there is a definite tendency for the readings to spike near the bases of muddy units (Fig. 4.25 and 4.35 offer good examples), although in some cases, the spikes may appear near the top (Fig. 4.27) or middle (Fig. 4.31) of stratum 2A. Unit N109 E96 also has a very dramatic negative spike in the low-frequency reading at 92.80-92.75 m, in stratum $2D_2$, and units N109 E103 and N111 E101 have some indications of negative spikes in stratum 2D.

There are also prominent negative spikes in stratum 1 in units N109 E103, N111 E101, N112 E99, and N110 E102, although only the latter extends deep enough into stratum 1 to demonstrate this clearly. This negative trend in chi values is probably due to past waterlogging of the sediments. Waterlogged sediments typically show reduced magnetic susceptibility due to loss of iron or conversion to non-ferrimagnetic forms (Maher 1998:47-48; Gale and Hoare 1991:214; Weston 2004; Grimley, Arruda and Bramstedt 2004). Unit I at the Wilson-Leonard site furnishes a good archeological example (Takac and Gose 1998:Fig. 28-1).

Vertical distribution of the coefficient of frequency dependency seems to be less patterned. There is a well-defined positive spike at the top of stratum 1, in the calcrete zone in unit N110 E102 (Fig. 4.27, lower right panel), but otherwise the coefficient shows few interpretable trends. Values are conspicuously negative in unit N109 E96, which is likely to be the unit closest to a source of groundwater saturation. The value of the coefficient is often taken as an indication of the proportion of pedogenically formed (rather than detrital) ferrimagnets.

Organic Carbon Content

The bench sediments contain very low levels of organic carbon. An attempt was made by Michael Marchbanks at the UTSA-CAR archeology lab to determine organic carbon content by the loss-on-ignition method for a column of samples from N109 E103 and N110 E102, but it was unsuccessful. The procedure is described in Appendix 2. After the analysis was completed, I discovered that the weight loss on ashing for each sample was heavily correlated with its clay and silt content. The bench sediments contain so much clay and silt that they are significantly hygroscopic. Ashing of the sediment samples simply drove off the bound water, and nearly all the weight change was due to water loss rather than organic carbon loss. Any actual weight change due to carbon loss was so trivial in comparison as to be undetectable.

Four much larger samples of sediment were later processed by Geochron Laboratories for radiocarbon assay, and careful processing of much larger volumes of sediment established that organic carbon content was indeed very low.

Coarse Clastic Material

Coarse clastic debris found in the bench deposits falls into three categories:

1) colluvial outwash deposits restricted to N109 E96, dominated by calcareous material;

2) isolated clasts scattered through all other excavation units in various strata, dominated by calcareous material;

3) lenticular pockets of chert gravel strewn along a conspicuous bedding plane (stratum 2E) exposed in the cutbank.

Much of the coarse clastic material found in the bench sediments is calcareous in composition and consists of Goliad sandstone (fine to coarse-grained quartz sandstone with white calcareous cement), fissured sandstone, fine-grained white or cream-colored marly or limestone-like clasts, calcareous petrified wood, and cream-colored to light gray caliche nodules. Sandstone clasts are usually friable and rounded, not angular. All of this material appears to intergrade visually, and in practice I found it impossible to reliably separate caliche nodules from Goliad Formation debris. I tentatively regard the caliche nodules as clastic (reworked from older deposits upstream) rather than autochthonous in origin (see discussion below).

Aside from the concentrated colluvial lenses of coarse-grained outwash gravel found in unit N109 E96 (Table 4.6), there are scattered, isolated or clustered clasts found elsewhere in the bench deposits. A few of these are probably chunks of sandstone or chert pebble manuports introduced by human agency, but most probably represent coarse colluvial debris sheetwashed or rolled onto the floodplain surface from the adjacent valley slope. In general, coarse clastic material becomes less abundant moving southwest to northeast across the excavated units. Chert gravel is about 11 times as abundant in N109 E96 as it is in any of the other units, and calcareous debris (Goliad sandstone and caliche nodules) is almost 15 times as abundant, undoubtedly because N109 E96 is likely positioned close to the buried valley wall. Table 4.5 shows that the density of coarse clastic material (chert gravel, Goliad sandstone, caliche nodules) tends to be higher in the sandy strata than in the muddy strata, as long as unit N109 E96 and its outwash lenses are omitted from the averages. If that unit is included in the averages, the relationship no longer holds. Inspection of the data plots for the individual units (upper left panel in Fig. 4.25, 4.27, 4.31, 4.35, and 4.40) confirms that densities are usually (but not always)

reduced in the muddy units and tend to peak in the sandy units, except in N109 E96. In a number of cases, spikes in coarse clastic debris match spikes in rhizoconcretion or ferromanganese concretion density. Since these items are thought to be diagenetic, not clastic in origin, the spikes might be the result of screener bias (a more conscientious screener taking over from a crew member who was less conscientious).

Most of the above material, then, is interpreted as colluvial debris derived from weathering of Goliad formation bedrock that surely must have been exposed somewhere to the south and southwest of unit N109 E96 in the late Pleistocene and early Holocene. This presumably includes a significant amount of Miocene chert gravel released by weathering from that bedrock. However, there are also pockets of chert gravel, mostly near the cutbank, in stratum 2E that represent coarse-grained bedload material lofted out of the creek channel and deposited on the floodplain surface by major flood events. Anyone who has examined creek floodplains after severe floods has probably seen gravel lobes like these overlying recently buried vegetation on fine-grained floodplain surfaces. Knox (1993) has used buried cobble and boulder deposits like these to track major floods throughout the second half of the Holocene in southwestern Wisconsin. According to Ritter (1975:646-647) bedload gravel can exit the channel either by rolling and saltating up the surface of enchannel bars, or occasionally in momentary suspension in very high-energy floods. Most examples seem to be associated with smaller creeks (for example, Costa 1974:Fig. 1), but Ritter and Blakley (1986) also report large gravel lobes (with gravel up to about 5 cm in diameter) from flooding on the Gasconade River in Missouri. Gravel lobes tend to occur as elongate bars, subparallel to the stream axis, and are plano-convex in cross-section along their transverse axes. The gravel pockets visible in the Coleto creek cutbank are not obviously plano-convex, but they have probably been

sectioned longitudinally by erosion, and may have been affected somewhat by sediment compaction. Ice-rafting can also emplace coarse debris (Moody, Pizzuto, and Meade 1999:301; Fig. 8) but is unlikely here, either in the Pleistocene or Holocene.

Extreme floods create macroturbulence that can transport boulder-sized clasts and carry gravel out of the channel into depositional facies where bedload would not normally be found. The most extreme examples come from bedrock-floored, high-gradient streams on the Edwards Plateau (Baker 1977:Fig. 17). Lower gradient, alluvial floored coastal plain streams like Coleto Creek have much lower, but still significant transport capabilities. The lag deposits of chert cobbles seen in interdune areas directly across the creek from the bench (perhaps introduced by Hurricane Beulah in 1967) are adjacent to the channel proper and have perhaps not been lofted any significant distance, but chert cobbles seen on the Preiss Ranch Lower (?) Post-Beaumont terrace surface (Fig. 4.6) sit well above the present channel. These cobbles (probably reworked from Willis Formation deposits) are much larger clasts than those eroding from the gravel pockets at the top of the bench, and reflect the magnitude of contemporary Holocene flood events.

The line of gravel pockets marking the top of the bench sediments is probably a stratigraphic marker for beginning of large-scale Holocene flood events in the Coleto Creek basin. These were most likely major subtropical storms generated by a nearby hurricane landfall, or a major storm event triggered by a fastmoving spring or fall Arctic front colliding with overriding Gulf moisture. Both kinds of events are characteristically Holocene events that could happen only after 1) sufficient warming of Gulf water temperatures in the early Holocene or 2) removal of Arctic front blockage by melting of the Laurentide ice sheet.

Fossil Wood

Small fragments of fossilized wood (unidentified) were found scattered throughout the bench deposits. These have a chalky, calcareous, cream-colored exterior, often with a harder, light gray-brown interior, and occasionally patches of the typical gray micritic carbonate cement that permeates all the bench deposits are found adhering to the exterior surface. The mineralized wood and the adhering cement have a very different appearance. This fossil wood superficially resembles and was mistaken for travertine during the excavations and initial lab cataloging, and was identified as mineralized wood only after thin sections were examined. The age of the wood is unknown, but I suspect it is most likely Miocene, and derived from the Goliad Formation, based on the thorough mineralization and the pervasiveness of calcareous mineralization in that formation. It was cataloged separately (as "travertine") in lab processing, but no effort has been made to study its distribution in the deposits.

There are some recurrent shapes among the wood fragments. Straight or twisted hemicylindrical shapes, often with one rounded end, are common. Two specimens from unit N112 E97 selected for thin sectioning are reasonably representative. The first specimen (93.14-92.75 m, 1/4-inch screen, bag 2, lot B-112) is hemicylindrical in section with one rounded end, 43.5 mm long, 22 mm wide, with a wall thickness of 4.5-8.0 mm, weighing 13.7 g (Fig. 4.75, upper photo). The second specimen (02.40-92.35 m, 1/4-inch screen, lot B-120) is a shorter, porous hemicylindrical section 26.5 mm long, 105-12.5 mm wide, 3-4 mm thick, weighing 1.4 g (Fig. 4.75, lower photo). Cellular wood structure can be seen in both transverse and longitudinal thin sections (Fig. 4.76, 4.77).

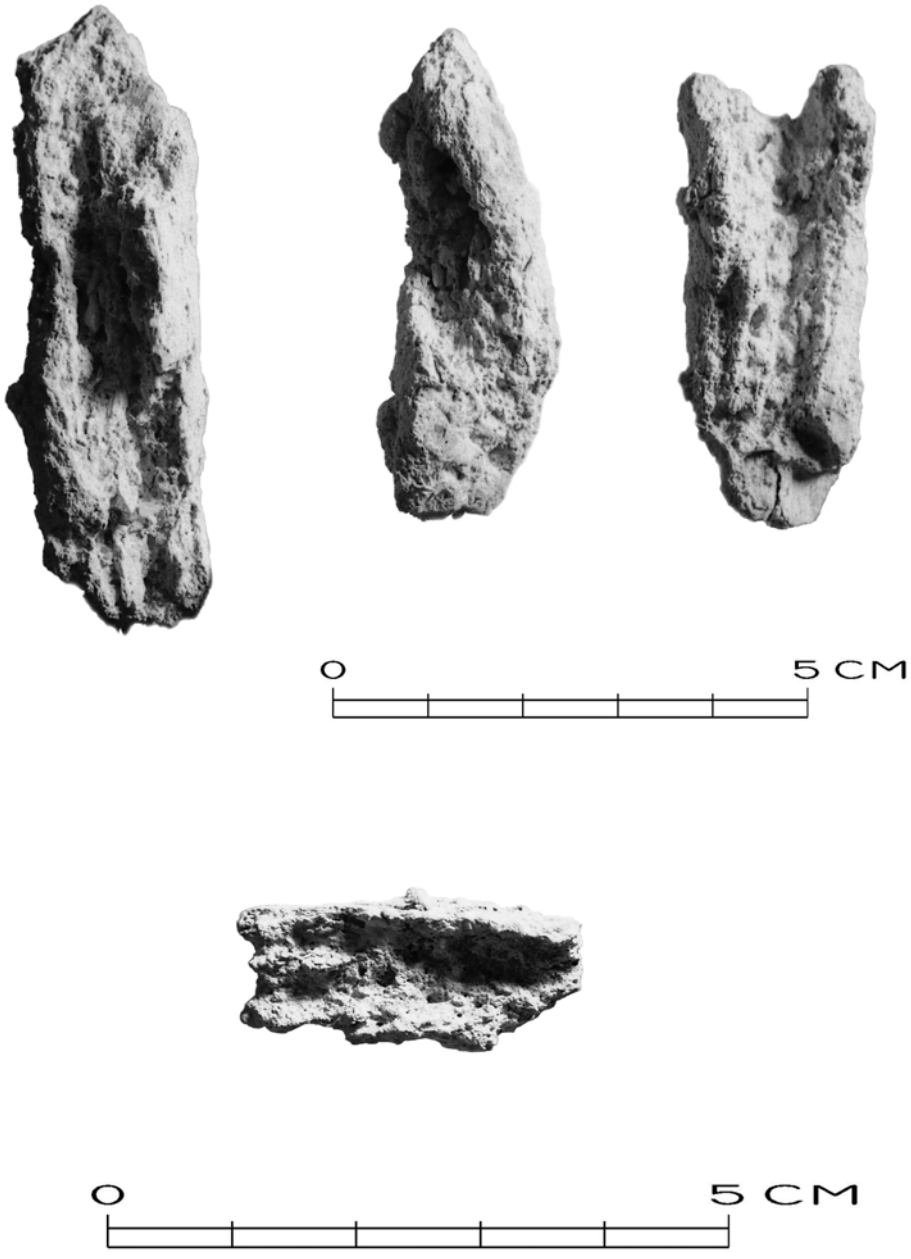


Figure 4.75. Fossil Wood Selected for Thin-Sectioning. Upper photo: N112 E97 (93.14-92.75 m), bag 2, specimen B-112; lower photo: N112 E97 (92.40-92.35 m), specimen B-120.

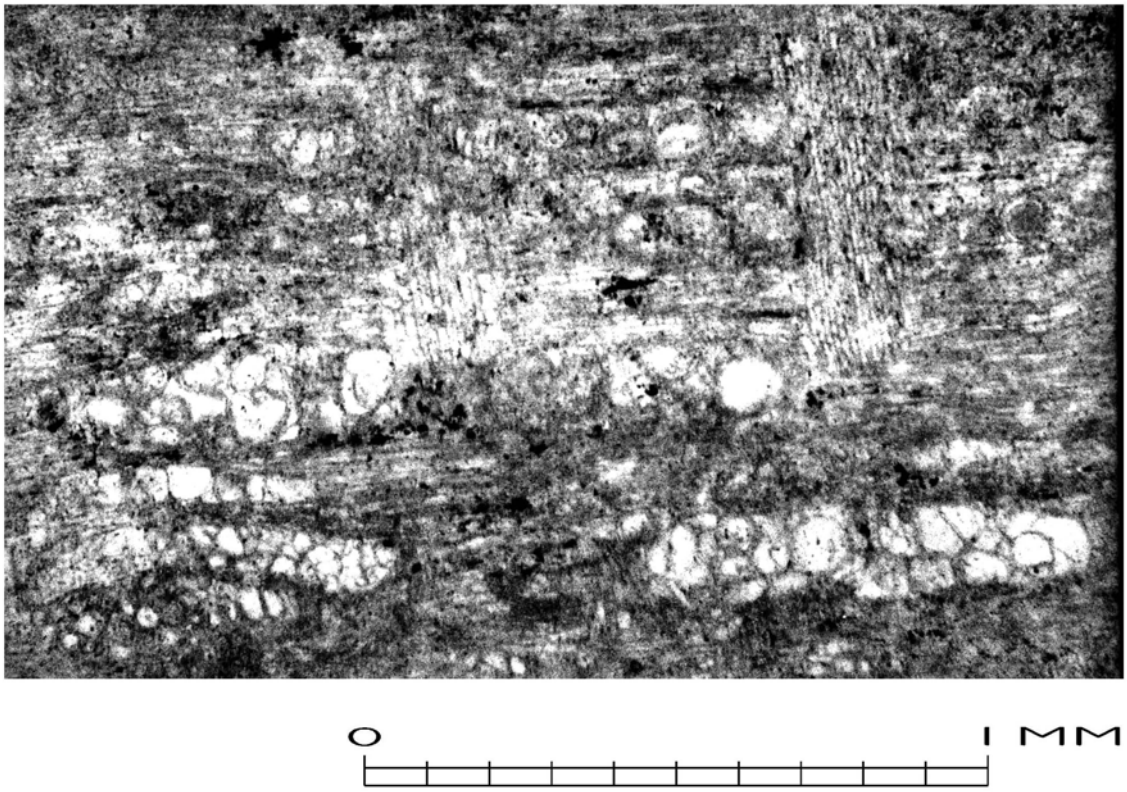


Figure 4.76. Thin Section of Fossil Wood. N112 E97 (93.14-92. 75 m), bag 2, specimen B-112. Longitudinal section with unpolarized light through one of the three specimens shown in Figure 4.75, top photo.

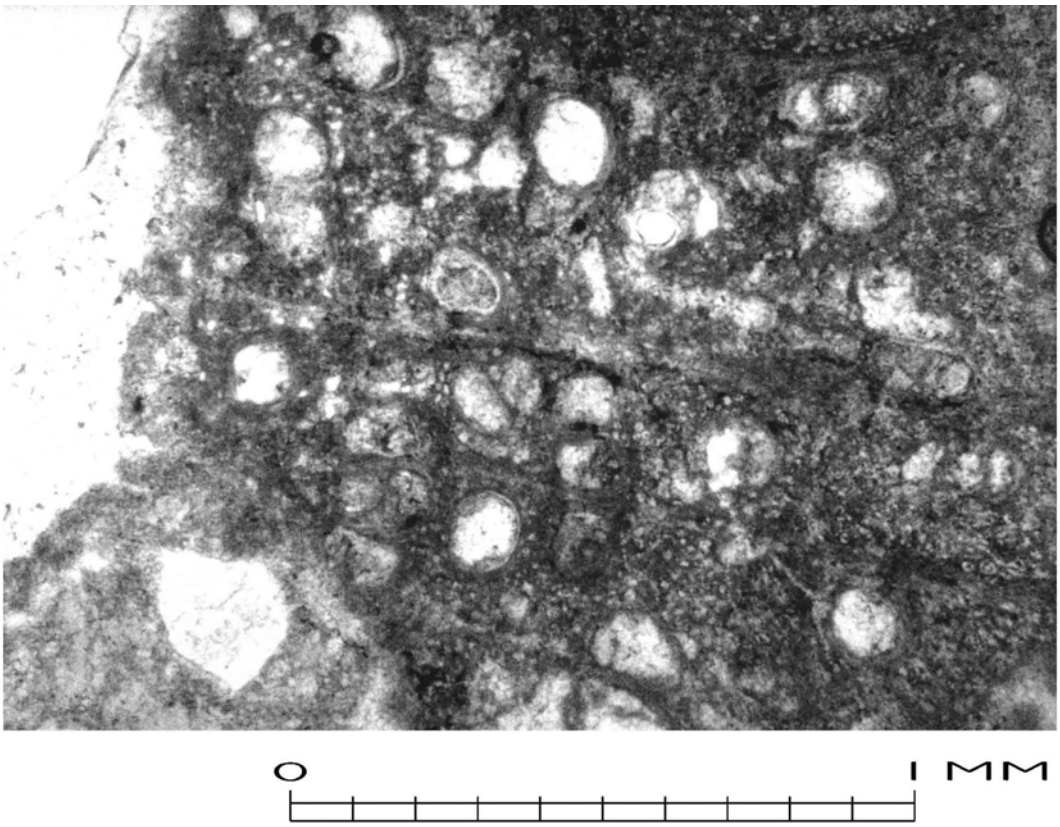


Figure 4.77. Thin Section of Fossil Wood. N112 E97 (93.14-92. 75 m), bag 2, specimen B-112. Transverse section (with unpolarized light) near interior surface, through one of the three specimens shown in Figure 4.75, top photo.

These items are regarded as fossils reworked from older deposits upstream and deposited on the surface by floods. They are relatively lightweight, and could probably be picked up and moved by running water rather easily.

DIAGENETIC PROPERTIES OF THE BENCH SEDIMENTS

The interpretation offered here is that the bench sediments accumulated very slowly (over two millennia or more) by vertical overbank accretion, with no visible removal of sediments by erosion. A slowly aggrading surface like this would ordinarily

provide a site for extensive soil development with conspicuous horizonation, but the bench sediments were persistently saturated by groundwater, which served to greatly retard weathering and soil development except perhaps during limited seasonal drying episodes. There are only limited indications of soil development, mostly appearing toward the top of the bench (especially in stratum 2D) as seasonal drying became somewhat more pronounced during the transition into the Holocene.

Aside from oxidation, many of the most important weathering processes associated with soil development (such as translocation of clays, sesquioxides or carbonates) are the result of vertical movement of vadose water in well-drained sediments (Birkeland 1984:120-144). Frequent or near-constant groundwater saturation, however, prevents both oxidation and vertical movement of illuvial clays, iron minerals, and pedogenic carbonates. Instead, most of the diagenetic features seen in the bench sediments are those related to groundwater saturation and movement: phreatic carbonate cement, abundant rhizoliths, and movement and redistribution of iron, manganese and uranium minerals. The two very fine-grained strata (2A and 2C) near the middle of the section may also have tended to restrict water movement to horizontal rather than vertical movement. Stratum 2A, in particular, may served at times as an aquitard.

Aslan and Autin (1998) studied Mississippi River floodplain soils near Natchez, and the part of their study that deals with backswamp deposits serves as a useful model for interpreting fine-grained sediments that are frequently saturated. The scale of the floodplain and the source of waterlogging differs from the Berger Bluff case, but the study is still relevant. They found that backswamp soils form in less than 5400 years, mottles and slickensides develop in tens to a few hundreds of years, and poor drainage

and slow but continuous sedimentation inhibits weathering. Soil chemistry is largely controlled by depositional differences in parent material, rather than by weathering processes (Aslan and Autin 1998:443). Calcite and gypsum precipitate from groundwater during seasonal rise and fall of the water table (Aslan and Autin 1998:445), rather than from downward movement of vadose water.

Various Forms of Carbonate

Carbonate occurs in several different forms. Nearly all of it has been mobilized from the Goliad Formation aquifer, carried in solution by groundwater, and deposited somewhere in the bench sediments. There are, however, no known examples of travertine. Travertine usually forms where outflowing water is aerated and degassed by flowing downward over rocks. Likewise, dispersed microscopic pedogenic calcite (?) needles, seen in the upper deposits, do not seem to be present in the bench deposits. Jim Abbott's (2001:Appendix II) remarks on secondary carbonates in the Texas coastal plain environment can be profitably read in conjunction with this section.

Phreatic carbonate matrix cement: This light gray, micritic carbonate is pervasive throughout the bench deposits, filling pores between sediment grains and lining voids in the matrix. For the bench as a whole, it represents about 17.83% by weight of the matrix (range, 10.52-30.52%, standard deviation, 4.99%). Its role in creating the indurated benchlike landform at the site has already been mentioned, but once emplaced, it has also served to prevent bioturbation by plants and animals, and it has also served as an ionic buffer for animal bones and freshwater mussel shells, providing an alkaline environment that has helped to preserve them. It also encrusts and penetrates small bits of wood charcoal found in the sediments, and must be thoroughly removed to allow accurate

radiocarbon assay of charcoal and sediments. Since the proximate source is the Goliad Formation bedrock, the carbonate is assumed to have no measurable radiocarbon activity. It is most abundant in stratum 1 and declines slightly above stratum 2A, increasing again somewhat near the top of the bench. When damp, the carbonate gave the stratum 1 sediments the consistency of damp, partly hardened concrete or mortar, difficult to dig with a trowel. In stratum 1, cream-colored carbonate forms wavy crosslaminations that appear in all the profiles (Fig. 4.28, 4.29). These probably represent deposits that formed along wetting fronts in the sandy sediments, and may be carbonate analogs of clay illuvial bands that are often seen in seasonally saturated sandy sediments. They have the same shape in profile.

Groundwater carbonates can be precipitated either below the water table or above it in the capillary fringe zone. Precipitation can be triggered by an increase in calcium ions, removal of water by plant roots, and removal of CO_2 by bacteria or by degassing through matrix pores (Wright and Tucker 1991:7, 8).

Laminar carbonate ("calcrete zone'): Seen only in N110 E102, this 5-13 cm thick cream-colored calcrete zone (2.5Y 6.5/2 moist) directly underlies stratum 2A (Fig. 4.26). There is no indication it formed as a pond deposit or as a subaerial travertine deposit, or as a pedogenic caliche deposit. The clay-rich stratum 2A capping it probably served as an aquitard confining groundwater movement, but allowing its deposition somehow.

Carbonate pans: Flatlying panlike or other irregular hard masses of carbonate (up to 10 cm or so in horizontal extent) were occasionally encountered in the excavations. These were composed of quartz sand cemented by the same gray, micritic carbonate making up the rhizoconcretions found in the sediments. They were uncommon and simply seemed to

be areas with especially dense accumulations of phreatic cement. As a rule, these were well enough indurated that they could be removed from the sediments without breaking up.

Carbonate encrustations on inclusions: Most of the objects recovered from the bench, whether chert flakes, chert pebbles, bone fragments, fired clay nodules, or wood charcoal fragments, have small patches of gray phreatic carbonate adhering to the surface, acquired after burial. In many cases, the carbonate has a threadlike tubular shape suggesting it was deposited where plant rootlets enclosed buried objects.

Carbonate webbing, filaments, or films: Unfortunately, I made no systematic observations on this form. My impression is that carbonate filaments are not very abundant, but are probably much better developed in stratum 3 and above, into the upper deposits.

Rhizoconcretions: These are individual fossils that can be extracted intact from the enclosing matrix, as opposed to root stains that break up when the matrix is excavated. Klappa (1980) uses the generic term "rhizolith" to refer to preserved root fossils, and uses the term "root tubule" to refer to cemented cylinders around root molds. I have not followed Klappa's terminology, preferring to use the terms "rhizoconcretion" and "rhizolith" interchangeably to refer to these root tubules. In any case, they appear to form as indurated calcium carbonate encrustations that form around living plant rootlets (possibly in association with soil bacteria or fungi) as the rootlet draws groundwater from the enclosing sediment, and may continue to accrue after the rootlet has died. The exact nature of the process is still unknown. Krinitzsky and Turnbull (1967:33) attribute it to

removal of CO_2 from groundwater by roots and/or increase in saturation of carbonate in groundwater, but Klappa (1980:625-628) seems to dispute this viewpoint. Abbott (2001:204) suggests they form in matrix that is periodically saturated. However, similar rhizoconcretions are common in loess (see Krinitzsky and Turnbull 1967:Fig. 1), where they may be associated with grass rootlets.

Rhizoconcretions are abundant and ubiquitous in the bench deposits. The individual fragments were recovered by the thousands from the 1/4-inch screen. They vary somewhat in diameter, shape, and fragmentary length, but most are somewhat narrower than a pencil, generally 3.2-3.8 mm in diameter, and composed of hard, light gray-brown micrite similar to that serving as matrix cement (Fig. 4.78). The evidence seems to suggest that although the concretions are nearly as thick as a pencil, the fine rootlets (unidentified) that served as the original nucleation site were probably less than a millimeter in diameter. Thin sections made transverse to the long axis of six of these rhizoconcretions (N112 E97, 92.35-92.30 m) show they are composed of micrite (Fig. 4.79). Occasional sediment grains ("floating skeletal grains") may appear in the interior, but most sediment grains line the outside surface. Sediment grains seen in the interior of the rhizoconcretion are rare small to medium grains that are usually toward the periphery, not in the core area. A few examples of rhizoconcretions with a single very small central root channel can be seen, but more usually the transverse sections are riddled with highly irregular voids (compare with Klappa 1980:Fig. 5, d). There are usually two or three larger ones (0.7-1.4 mm maximum diameter) and many smaller ones (usually about 0.1-0.3 mm in diameter). These are assumed to be longitudinal channels, but I have no longitudinal thin sections to verify this. There are also occasional subrounded to circular channels (0.1-0.2 mm diameter), but they are much less common. Surrounding the small

channels, or sometimes extending transversely across part of the diameter of the rhizoconcretion, can be seen thin, light brown, linear cellular structures that may represent silicified root sheaths.

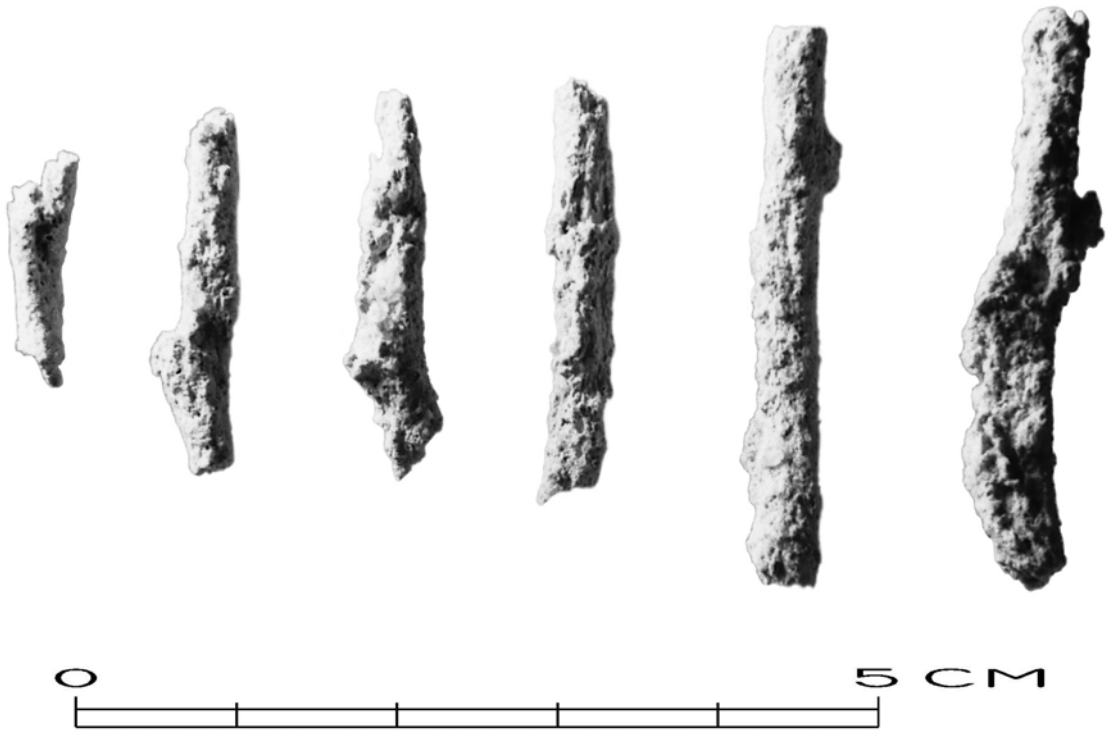


Figure 4.78. Rhizoconcretions Submitted for Thin-Sectioning. Six rhizoconcretions from unit N112 E97 (92.35-92.30 m), ¼-inch screen were epoxied as a group and sectioned transversely.

These extinguish completely in polarized light and may be composed of amorphous opalescent silica. A few examples (N112 E97, level 1) of contemporary rootlets growing through longitudinal channels in rhizoliths were seen; similar instances have been reported in the geological literature.

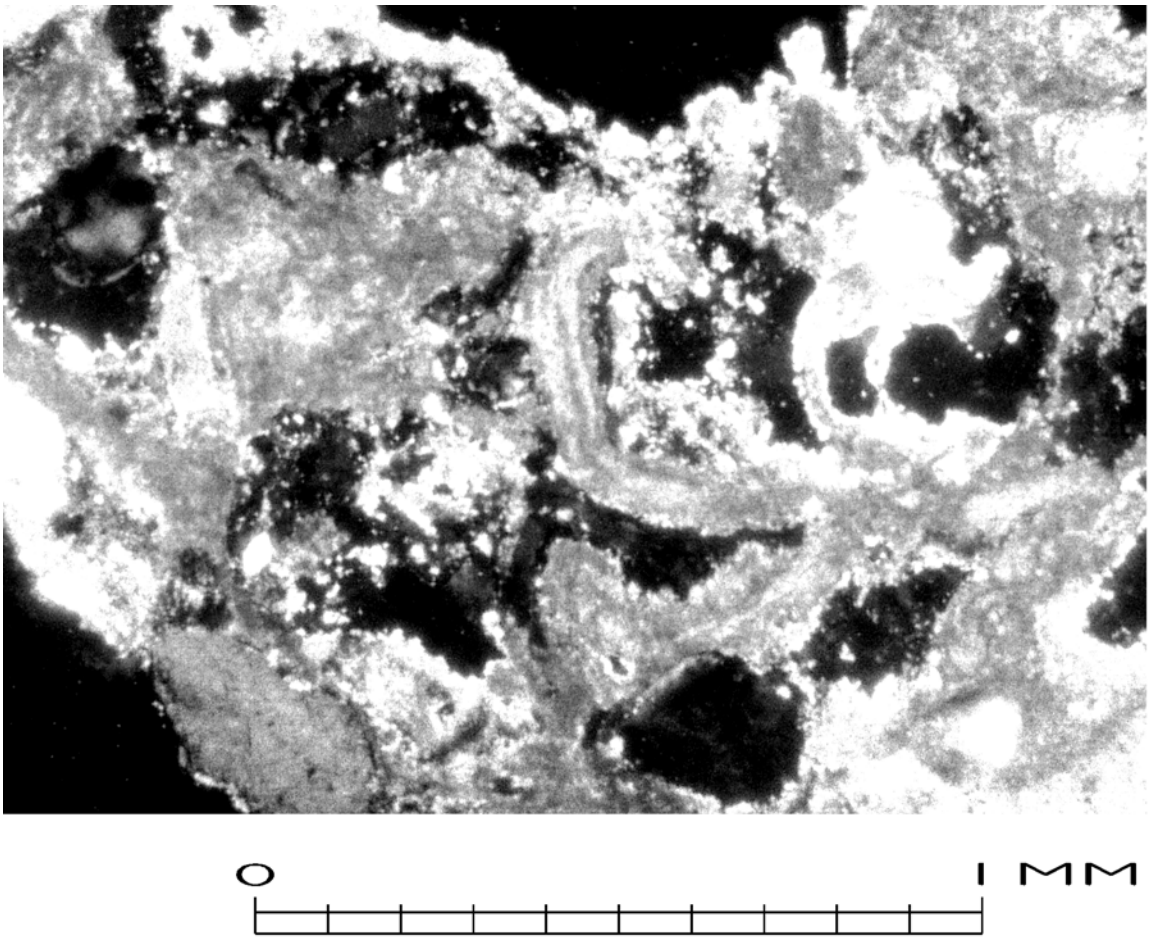


Figure 4.79. Rhizoconcretion in Transverse Thin Section. Part of the wall of a single rhizoconcretion from the group of six shown in the previous photo. Photographed through 5X lens in polarized light. Several subcircular longitudinal canals can be seen.

In addition to the pencil-sized rhizoconcretions, there are irregular fine root tubules about 0.8-1.0 mm in diameter, usually surrounding an open central void about 0.3-0.4 mm in diameter. These are fairly abundant, but essentially impossible to quantify. The central void is often surrounded by a white, caliche-like hypocoating that may or may not survive breakup of the matrix during excavation (Fig. 4.81).

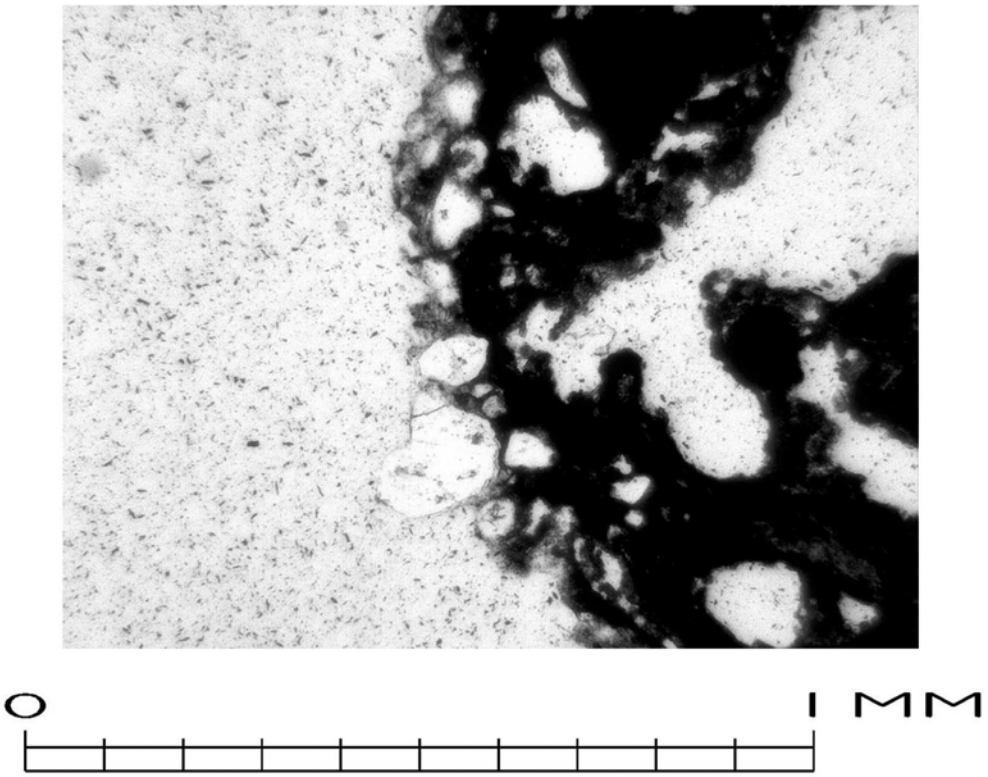


Figure 4.80. Rhizoconcretion with Attached Sediment Grains. Shown here is another rhizoconcretion in transverse section with several quartz grains both attached to the exterior surface and embedded in the interior. Photo in unpolarized light with 2.5X lens. Provenience is the same: N112 E97 (92.35-92.30 m), ¼-inch screen.

Density (weight per unit volume) of rhizoconcretions is shown in Table 4.5 and in Figure 4.25, 4.27, 4.31, 4.35, and 4.40. Density is highest at the base (stratum 1) and top (stratum 3) of the bench and seems to follow that of other forms of carbonate. There is a very conspicuous peak in density immediately below stratum 2A, at the same level as the calcrete zone exposed in N110 E102. This peak appears in all of the four units that were deep enough to penetrate stratum 1. The reason for the increase in rhizoconcretion density at the top of the bench, during a period when spring discharge was apparently diminishing, is unclear. There are almost no data on density in stratum 3, but very large

numbers of rhizoconcretions were seen exposed on the eroded surface of stratum 3 at the beginning of the field project. There is no indication that these rhizoconcretions have a clastic origin, and they are assumed to represent evidence of very dense vegetation growing on the floodplain surface as the bench deposits accumulated. Unfortunately, I did not check the contemporary soil surface at the top of the bluff to see if contemporary rhizoconcretions were being formed there.

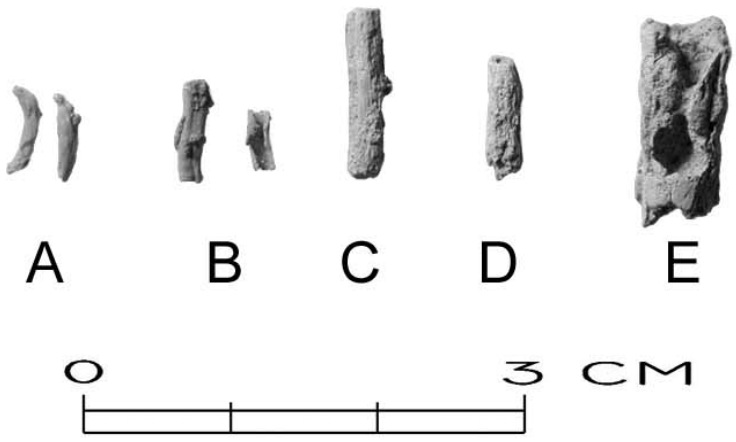


Figure 4.81. Minor Forms of Rhizoconcretions. A, N111 E101 (92.80-92.70 m), ¼-inch screen, two specimens; B, N110 E102 (92.15-92.10 m), matrix column, two specimens; C, N112 E97 (92.25-92.20 m), ¼-inch screen; D, N112 E97 (92.30-92.25 m), ¼-inch screen; E, N110 E102 (92.55-92.50 m), ¼-inch screen.

Root stains and casts: In addition to solidified light gray rhizoconcretions, there are also chalky, powdery white or off-white vertical and horizontal calcareous stains visible in the profiles of the various excavation units. These are often larger, perhaps 2 cm or more in diameter, and the larger examples can be traced downward for several centimeters, in

many cases crosscutting the stratum boundaries as marked on the profiles. These stains crumble and disappear when the fill is excavated, but they are well enough defined to show up faintly in photographs of the profiles (see tops of profiles in Fig. 4.28, 4.29, 4.32, and 4.33) and occasionally to appear in floors of units (Fig. 4.43, 4.49). Many of these stains are about the same diameter as or slightly smaller than crawdad burrows, but they probably represent a type of plant root larger than those responsible for the rhizoconcretions. These may be sites where roots have decayed, the void has filled with sediment that contrasts texturally with the enclosing matrix, and preferential infiltration of carbonate has then followed. Klappa (1980:620) calls these "root casts."

Caliche nodules: Carbonate nodules, varying widely in size, hardness, color, granularity and abundance were found in all the bench strata. Some of these resemble pedogenic ("caliche") carbonate nodules and are probably of Quaternary age, but as I have already remarked, there is so much overlap between these and the calcareous sandstone and marly carbonate nodules originating as colluvial debris from the Goliad Formation that it was impossible to sort them out consistently. Nodular carbonate forms in the bench deposits appear to be a mixture of some Quaternary material with a great deal of Miocene-aged material, perhaps ultimately also of pedogenic origin (Hoel 1982:105-113). Radiocarbon assays, luminescence assays of occluded single quartz grains, or carbon isotope studies would be required to sort out the age and origins of the different kinds of carbonate nodules.

Among the nodular carbonate material from the bench are a number of very hard, cream-colored light to gray nodules, usually highly fissured, (Fig. 4.82; compare with Abbott 2001:Fig. 59, C) that resemble pedogenic nodules. One of these (lot B-148, N109 E96, 92.05-92.00 m, stratum 2A) was submitted for thin-sectioning. It has a

homogeneous, very fine-grained calcite fabric with a few widely scattered, subangular floating skeletal grains; some of these are fairly large (Fig. 1.83). The exterior boundary is almost entirely free of attached matrix grains, except for one small area (Fig. 1.84). The nodule has branching radial fissures that are lined with secondary carbonate crystals (larger than those in the body of the nodule) and patchy, dark brown iron or manganese oxide stains.

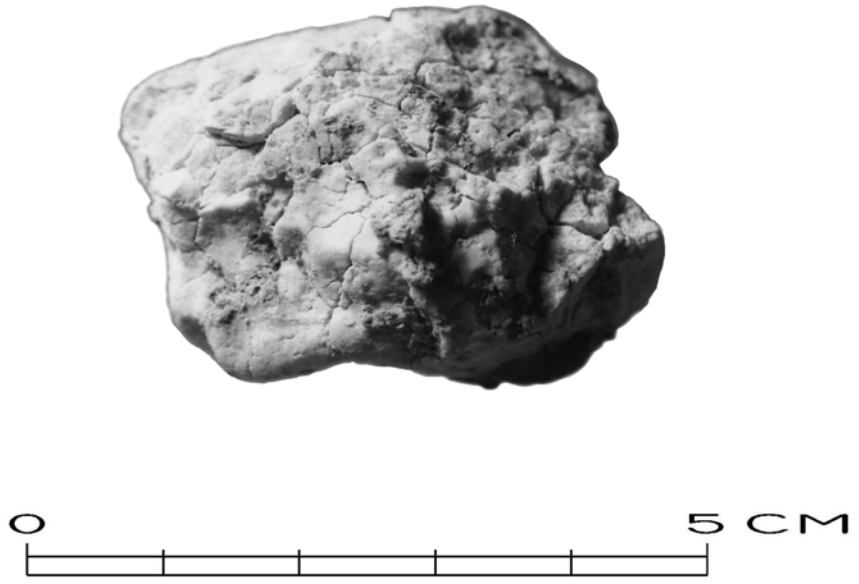


Figure 4.82. Caliche Nodule from Bench Deposits. The photo log for this lab photo is incomplete, but this is probably the specimen submitted for thin sectioning from N109 E96 (92.05-92.00 m), ¼-inch screen, slide B-148.

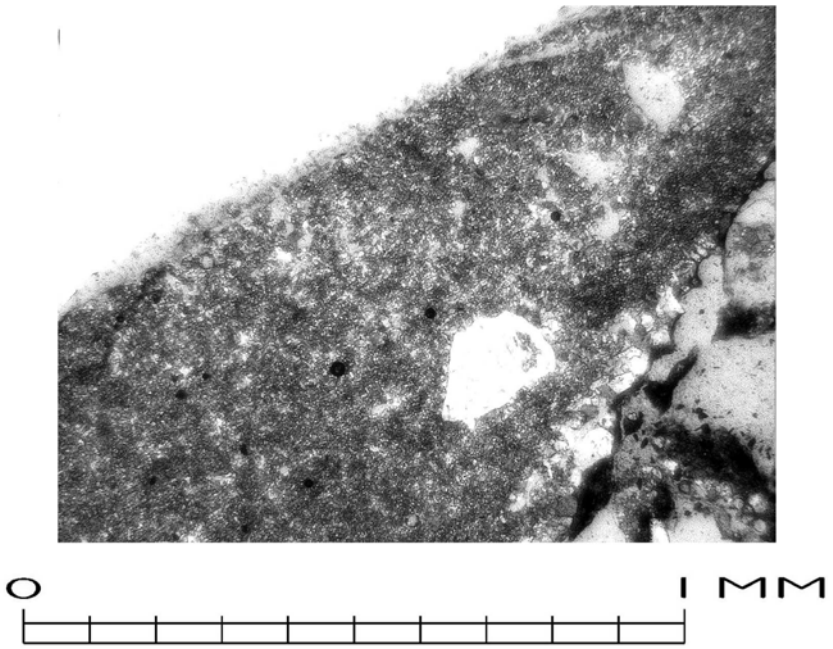


Figure 4.83. Thin Section of Caliche Nodule. Section through exterior boundary. Diagonal fissure with manganese staining in lower right corner; large floating quartz grain near center. Note fine-grained crystalline matrix and lack of attached sediment grains. Polarized light, 2.5X lens. N109 E96 (92.05-92.00 m), ¼-inch screen, slide B-148.

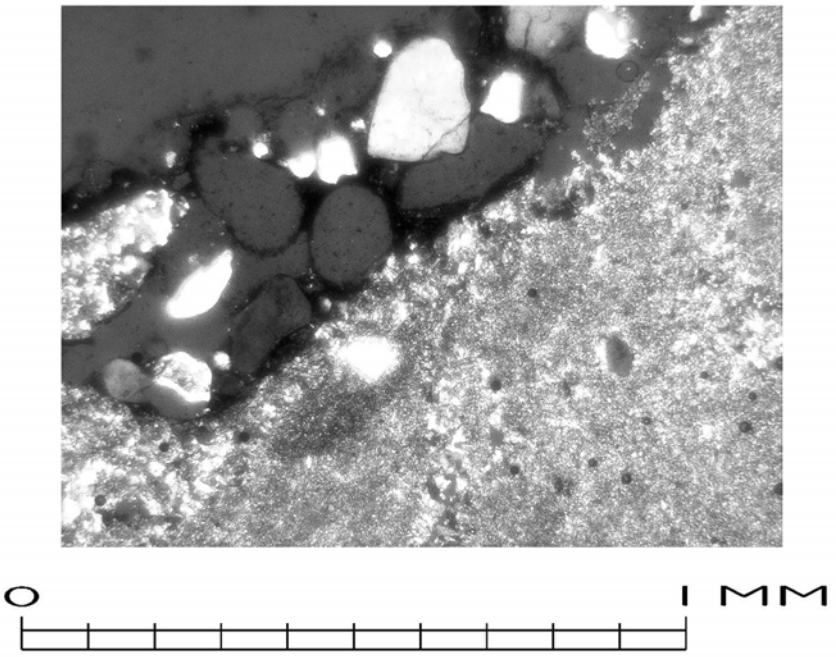


Figure 4.84. Thin Section of Caliche Nodule, Showing Attached Grains. Another view of the exterior boundary of the same nodule, this one showing attached sediment grains in polarized light, 2.5X lens.

These nodules may be reworked from older deposits like the Lissie terrace exposure upstream. Wright and Tucker (1991:14) use the term "allorthic nodules" to refer to nodules that are reworked from another source. Although these are probably pedogenic in origin, I do not think they are contemporary with the bench deposits. When they were encountered *in situ*, they were not surrounded by any kind of carbonate matrix halo. In each case, the boundary between the nodule and the surrounding matrix appears to be clear and sharp. This contrasts with the rhizoconcretions, whose exterior surfaces resemble the matrix from which they were excavated. I have tentatively interpreted these nodules as evidence of reworking, rather than pedogenesis. Some kind of chronometric analysis is needed to resolve their origin. Caliche nodules from the Lissie terrace scarp

upstream are very irregular in shape, white to cream-colored, with a finely botryoidal surface texture (Fig. 4.85).

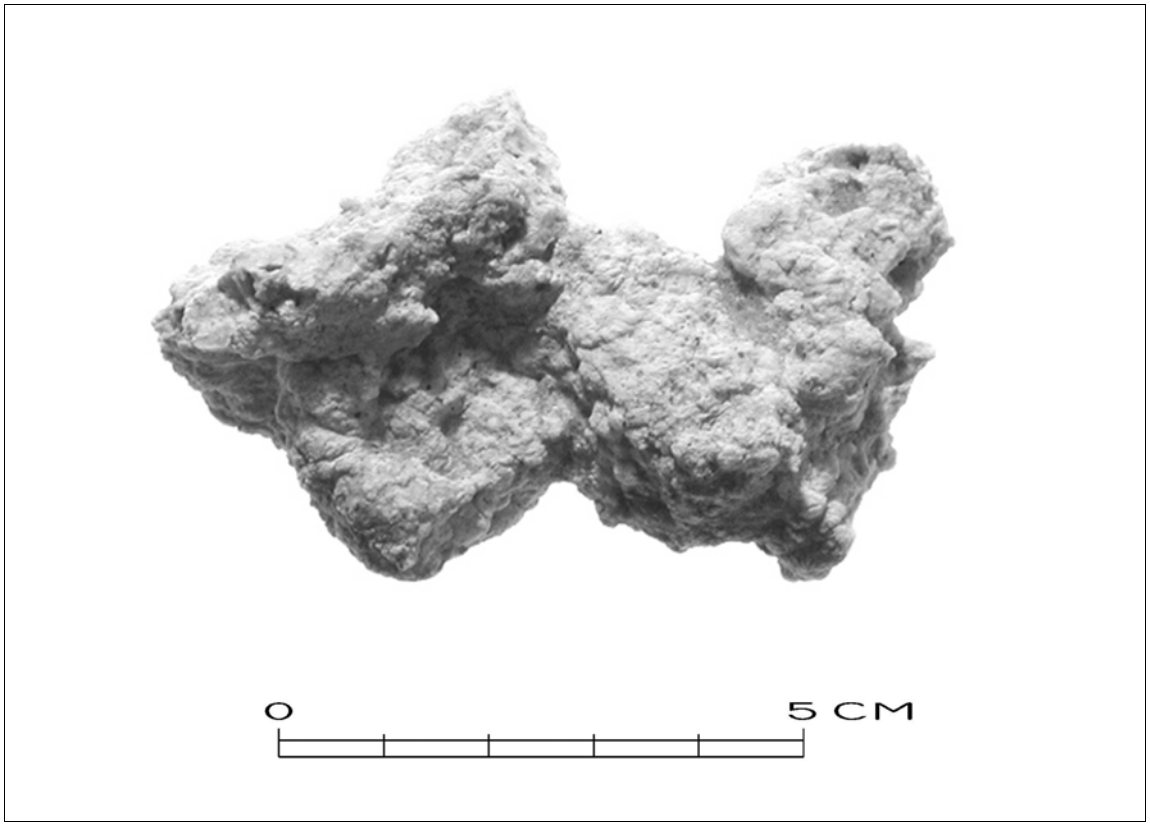


Figure 4.85. Caliche Nodule from Lissie Terrace. This specimen was collected from an exposure upstream from the bench and is less dense and more earthy in texture than most of the examples from the bench.

Redoximorphic Features and Precipitates

From redox (reduction-oxidation) indicators in the sediments, it is clear that the bench deposits were saturated with groundwater much of the time, although oxidation features also indicate there was some seasonal drying, particularly in the upper part of the bench.

Munsell matrix colors: The bench sediments, except for strata 2E and 3, are overwhelmingly gray. The gray color derives from the pervasive gray micritic cement, from the gray color of the clays in the sediments (especially strata 2A and 2C), and from frequent reducing conditions resulting from groundwater saturation. Soil scientists often judge that gray matrix colors indicate seasonal saturation for more than 50% of the year (Jacobs, West, and Shaw 2002). Table 4.11 lists field-recorded Munsell colors. Unfortunately, few colors were recorded in the field because a Munsell book was not always available.

There is little variation in hue or chroma throughout the stratigraphic sequence. What little variation occurs is mostly in color value, with very slightly lighter values toward the top of the section. Table 4.12 lists Munsell colors recorded in the lab on archived phtyolith/pollen samples from N110 E102, using a blue-filtered incandescent light that is intended to emulate natural light. Hue varies by about one Munsell unit (samples below 91.90 m have a slight pinkish cast), value varies by about one unit, and chroma varies by about half a unit. Stratum 2E has a slight yellowish tint and is lightly mottled with iron stains. Stratum 3 has a distinctive chocolate-brown tint. This slight color change at the top of the bench is probably due to the reduction in spring discharge at the onset of the Holocene. The two prominent dark bands seen in section (strata 2A and 2C) are dark because of increased clay content, not organic content, and the moisture and disseminated manganese dioxide associated with the clay.

Table 4.11. Field-Recorded Munsell Values.

Stratum	Excavation profiles	Cutbank
3	8YR 6.5/3 dry	
2E		10YR 6.5/3.5
2D	8YR 6.5/2 dry	2.5Y 6.5/2 dry
	7YR 5.5/3 mottled brown	2.5YR 7.5/1 dry
	to gray 10YR 6.5/2 root stains	10YR 5/4 dry mottles
	$2D_1$: 10YR 5.5/2	
	$2D_2$: 10YR 6.5/2	
	$2D_3$: 10YR 6.5/2.5	
2C	10YR 5.5/1 moist	2.5Y 6.5/2 dry
	10YR 5.5/1.5 gray with	
	7.5YR 4.5/4 mottles	
	10YR 5.5/1.5	
2B	10YR 5.5/1.5 moist	2.5Y 6.5/2 dry
	10YR 6.5/2	
2A	10YR 4.5/1 moist	2.5Y 5.5/2 moist
	10YR 6.5/2	
	2.5Y 7/2 loose matrix	
	10YR 5.5/2	
calcrete zone	2.5Y 6.5/2 moist	
1	2.5Y 5.5/2 moist	

Table 4.12. Munsell Colors for Archived Phytolith/Pollen Samples, N110 E102.

Sample elevation (m)	Dry color	Moist color
92.90-92.80 upper sample	10YR 6.5/2	10YR 4.5/2
92.90-92.80 lower sample	10YR 6.5/2	10YR 5.5/2.5
92.80-92.75	10YR 6/2	10YR 5.5/2.5
92.75-92.70	10YR 6.5/2	10YR 5.5/2
92.70-92.65	10YR 6.5/2	10YR 5.5/2
92.65-92.60	10YR 6.5/2	10YR 4.5/2
92.60-92.55	10YR6/2	10YR 4.5/2
92.55-92.50	10YR 6.5/2	10YR 4.5/2
92.50-92.45	10YR 6.5/2	10YR 4.5/2
92.45-92.40	10YR 6/2	10YR 4.5/2
92.40-92.35	10YR 5.5/2	10YR 4.5/2.5
92.35-92.30	10YR 5.5/2	10YR 4.5/2.5
92.30-92.25	10YR 5.5/2	10YR 4.5/2
92.25-92.20	10YR 5.5/2	10YR 4/2
92.20-92.15	10YR 5.5/2	10YR 4/2
92.15-92.10	10YR 5/2	10YR 3.5/2
92.10-92.05	10YR 5/1.5	10YR 3.5/2
92.05-92.00	10YR 5/1.5	10YR 3.5/2
92.00-91.95	10YR 6/2	10YR 3.5/2.5
91.95-91.90	10YR 6/2	10YR 4/2
91.90-91.85	9YR 6.5/2	9YR 4.5/2
91.85-91.80	9YR 6.5/2	9YR 4.5/2.5
91.80-91.75	9YR 6.5/2	9YR 4.5/2
91.75-91.70	9YR 6.5/1.5	9YR 4.5/2
91.70-91.65	9YR 6/1.5	9YR 4.5/2
91.65-91.60	9YR 6.5/1.5	9YR 4.5/2
91.60-91.55	9YR 6.5/2	9YR 5.5/2.5

Although there are no true blueish or greenish gley colors, the gray cast of the bench sediments suggests iron-manganese depletion.

> The relationship of color and wetness is explained largely by the oxidation-reduction cycles of Fe and Mn…. Reduction in soils is essentially a biological process…. When the supply of O_2 in the soil is depleted, anaerobic organisms take over and dehydrogenate soil organic matter. The H atoms lost in this process consist of a proton H^+ and electron e^-, so the process is considered to be oxidation of organic matter. Electrons produced are donated to Mn^{3+}, $Fe3^+$, $SO^{2-}_{4,}$ etc. which become reduced to Mn^{2+}, Fe^{2+}, and S- (as sulfide)…. Because Fe^{2+} is relatively soluble, Fe losses occur by leaching during the reduction cycle. Gray colors are mainly caused by a lack of Fe-oxides. In contrast, the yellowish brown color of soils is due mainly to goethite, and the reddish color to hematite (Evans and Franzmeier 1988:354).

Ferric (Fe_2O_3) iron is a strong coloring agent, but ferrous (Fe O) iron is not, so the acquisition of the extra electron has a significant effect on color. Fluctuating water tables cause the sediment state to alternate between oxidation and reduction, and this typically causes mottling. Reduced sediments can also oxidize and change color when exhumed and exposed to the air, but no instances of this were observed during fieldwork at the site.

Sediments exposed in the cutbank had a very slight pinkish cast, especially in stratum 1, which is why colors recorded from the cutbank are listed separately in Table 4.11. The pinkish cast was not noticed in profiles of N110 E102, but it does appear in archived phytolith/pollen samples at 91.90 m and below (see Table 4.12). The pinkish cast may be due to iron oxides associated with carbonate cement. There also might be some introduction of rubified sediments from the Lissie Formation in this area.

Iron and manganese stains: All of the bench strata are mottled to some extent with yellowish-brown (for example, 10YR 5.5/3 in stratum 2D) to brown (7-7.5YR 4.5-5.5/3-4) stains which become progressively darker and more compact toward the base of the

section. These are sites of ferromanganese accumulation (probably associated with bacterial oxidation) and indicate occasional seasonal drying of the sediments, but in all strata the percentage of profile area covered by stained areas is much smaller than that with gray sediments. Oxidation indicates that the sediments were aerated, not waterlogged, for at least part of the year. Soil scientists usually refer to large, diffuse oxide concentrations like these as "iron masses." Goethite, lepidocrocite, maghemite, ferrihydrite and similar minerals produce colors like these.

Manganese stains on bone: Bone fragments from the bench deposits very often have black or silver-black stains on the exterior surface. In cases where the stain covers the entire bone, careful microscopic examination is necessary to distinguish between staining and charring (examples of both have been seen). Although no mineralogical identification of these stains has been done, there are presumed to be manganese dioxide. Another possibility would be some type of uranium oxide, such as pitchblende (or uraninite).

Uranium oxide efflorescences (?): Porous items recovered from the bench deposits (mostly baked clay nodules and bones) frequently have an unidentified, faint yellow powdery exterior coating that may perhaps be carnotite or some other uranium oxide mineral. Impermeable items (such as chert pebbles or chipping debris) lack this coating. Uranium is known to exhibit preferential accumulation toward the exterior of bone (Millard and Hedges 1995). The Goliad Formation is a well-known uranium host (Hoel, 1982; Arredondo and Thomann 1996). Millard and Hedges (1995:Fig. 10) report that waterlogged sites have lower concentrations of uranium in bones than other kinds of sites, but I suspect that the sites they studied were not fed by an aquifer emerging from a major uranium host. No mineralogical studies have been done of these yellow coatings.

Manganese or uranium precipitates (?): Only a few uncommon, very small accumulations of silver black, vesicular-textured material were recovered from the sediments. Initially mistaken for charred plant matter or bone in the field, they were later examined microscopically and found to be unidentified mineral precipitates, perhaps some kind of manganese or uranium mineral such as birnessite or pitchblende. Unlike the coatings noted above, these are small aggregates that are not associated with porous inclusions. Very large accumulations of manganese and iron oxides are sometimes produced by bacterial oxidation around cold springs. Mustoe (1981) reports on one such locality where the soil contains about 43% MnO_2 and 20-30% Fe_2O_3 produced by bacterial oxidation. Nothing comparable to that was found in the bench sediments.

Ferromanganese concretions: Iron and manganese are chemically similar elements and are frequently found together in nodules and concretions. Ferromanganese concretions are small hard, spherical aggregates with concentric layers of iron and manganese oxides that form in soils subjected to periodic wetting and drying (White and Dixon 1996). According to Stiles, Mora and Driese (2001:943), they occur most frequently in silt or clay-rich soils with poor drainage under "moderate continental to warm subtropical temperature regimes" and are well formed within 3000-4000 years. However, I have seen preferential accumulation of very small, buckshot-sized ferromanganese nodules in the tops of postholes of Caddoan structures dating about 840-1255 cal AD at the George C. Davis site, which suggests that very small concretions conceivably can form in as little as 700-1100 years in favorable microsites and climates. Several kinds of manganese minerals like birnessite, rhodocrosite or lithiophorite and iron minerals like goethite or lepidocrocite may be involved. The iron content has been used as a measure of mean

annual precipitation during the formation of the concretions (Stiles, Mora and Driese 2001).

Ferromanganese concretions recovered from the bench deposits are commonly sand-sized to buckshot-sized, occasionally pea-sized. Although they are smaller than the 1/4-inch mesh spacing of the screens, the buckshot-sized concretions were recovered from the artifact screens in some numbers, probably because they were trapped by matrix. Recovery densities are especially high in the topmost strata (stratum 2D and 3; Table 4.5). The screen sample plots (Fig. 4.25, 4.27, 4.31, 4.35 and 4.40) show that in every unit, densities of ferromanganese concretions fluctuate widely, but closely track the density of chert gravel. This can only mean that either 1) the ferromanganese concretions are clasts, like the gravel, or 2) the densities of both gravel and concretions fluctuate chiefly as a result of variations in screener competence. Both explanations are possible, if not equally plausible. Different crew members worked the screens as most of the units were deepened, and their collection diligence was variable. Although the density of the concretions varies from stratum to stratum, no clusters were seen in the excavations – that is, there was no evidence that concretions were accumulating as clastic material in low spots or behind obstructions. A few concretions were present in the gravel deposits discussed above (in N109 E96 and in stratum 2E), but they seem to be less common there than in the rest of the deposits.

All of the excavated sediment passing through the 1/4-inch screen was collected from unit N109 E96 and later wet-screened through two finer mesh sizes, "coarse" and "fine" (window mesh). The coarse fraction from selected levels has been picked to extract microsnails, and ferromanganese concretions were also extracted from a few of the levels. As a result, large and presumably representative samples of concretions are

available for study from just a few levels in this one excavation unit. A single sample from the 92.35-92.30 m level was selected for study. As it happens, no ferromanganese concretions were recovered from the 1/4-inch screen in this particular level, but 1101 specimens varying in shape from spherical to oblong were counted from the coarse fraction passing the screen, and their diameter was measured. The median diameter is 2.00 mm and mean diameter is 2.19±0.76 mm (range 1.0-6.7 mm). Figure 4.86 shows the size distribution. The average size probably varies considerably in other levels, but no data are available. It is clear, though, that most of the concretions are small enough to pass through the 1/4-inch screen, and although the screen counts probably give a reasonable estimate of the level-to-level fluctuations in abundance, they do not give a very good estimate of absolute abundance. The same thing is probably true of any other kinds of geological or biological material smaller than the 1/4-inch mesh. To take another example, from the 93.08-93.00 m level in the same excavation unit, three concretions were recovered from the 1/4-inch screen, but another 1844 were recovered from the bulk matrix coarse fraction, plus 374 exfoliated fragments (these were counted, but only the largest spherical concretion, 6.8 mm in diameter, was measured).

Many of the concretions are spherical, others oblong, and some are more irregular, with somewhat pitted surfaces. They are not attracted to a magnet, and presumably have a higher manganese than iron content. Most are quite black (7.5 YR 1/1 is typical), with only a few brown (roughly 7.5YR 6/5) specimens. In addition to the 1101 spherical specimens in the 92.35-92.30 m level, there are an additional 118 exfoliated hemispherical to tabular fragments. Some of these have fresh breaks produced during excavation, but most do not. These might suggest that some or all of the concretions were formed elsewhere, exhumed by erosion, and deposited in the site as clastic material.

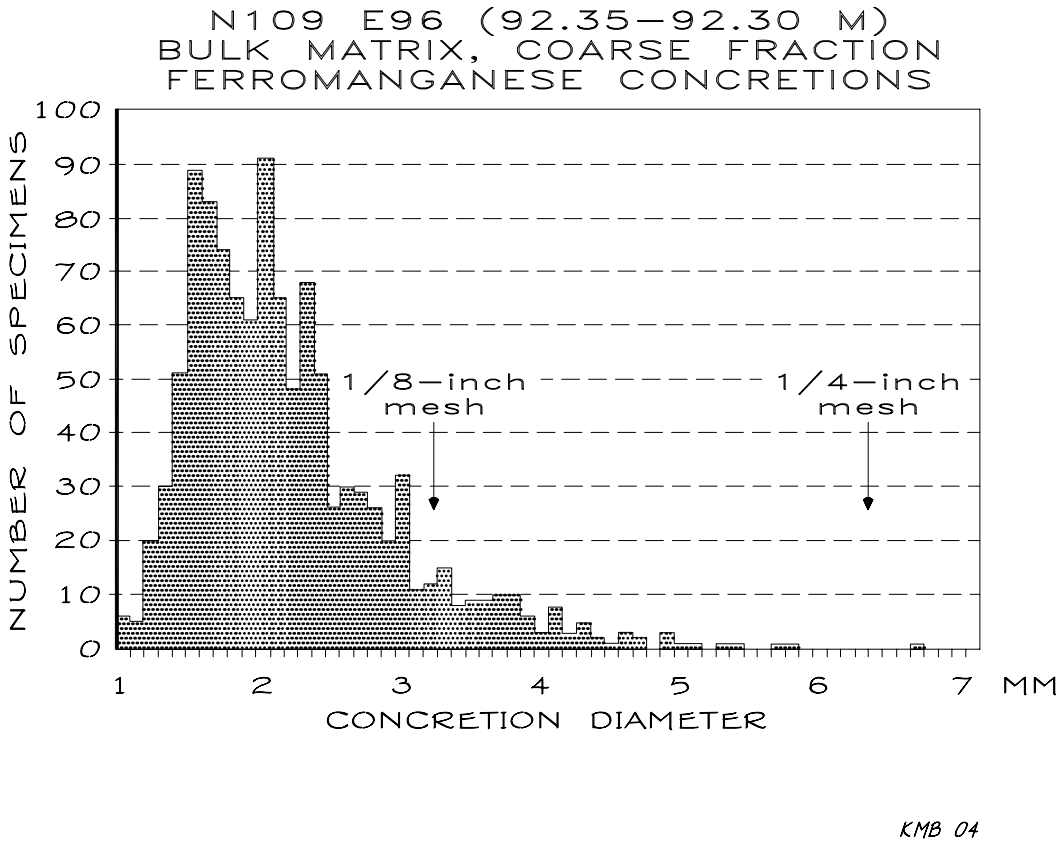


Figure 4.85. Size Distribution of Ferromanganese Concretions. Maximum diameter of spherical or subspherical concretions (N = 1101) extracted from fill passing the quarter-inch screen in a single 5-cm excavation level (upper stratum 2B) from N109 E96 is shown, along with limits of 1/8-inch and ¼-inch mesh. Exfoliated fragments are not included.

Some of the spherical concretions have rather coarse-grained sand grains attached to the exterior surface (under the microscope, these actually look like miniature armored mudballs). I have not measured the sand grains, but many of them appear to be coarser than the average grain size of the sand fraction in the bench sediments. A few concretions also have attached carbonate root tubules or thin surface carbonate coatings.

Animal and Plant Disturbances

Visible in the unit profiles are a few, somewhat larger disturbances in two of the sandy units, stratum 2B (Fig. 4.34 and 4.38) and 2D (Fig. 4.39) and one of the muddy units, stratum 2C (Fig. 4.38). These are interpreted as noncultural, perhaps animal burrows (possibly nest chambers of fossorial animals). They are not common, and none were noticed in the cutbank profile. There are also a number of vertical shaftlike disturbances a few centimeters in diameter that I have interpreted, above, as root stains. These perhaps show most clearly in Fig. 4.32. They are about the same diameter as crawdad burrows, but there is no evidence of the extensive underground chambers that are associated with crawdad burrows (Grow and Merchant 1980; Hobbs 1991: Fig. 22.17; Hobbs and Whiteman 1991) and I think they are much more likely to be root stains than crawdad burrows. There is no evidence of the extensive burrowing seen at the Aubrey site (Ferring 2001:Fig. 3.25) or the Burnham site (Dort and Martin 2003:Plate 4a). Remains of several kinds of fossorial animals (eastern mole, Attwater's or Texas pocket gopher, prairie or pine vole, northern grasshopper mouse, Ord's kangaroo rat, hispid pocket mouse, deer mouse or white-footed mouse, least shrew, and smallmouthed salamander) were found in the bench deposits, but most of these are believed to have been introduced from better-drained upland habitats or from more friable areas of the floodplain. Most of these burrowing taxa are known to prefer friable, sandy, clay-free soils that are not waterlogged, and would probably be excluded from burrowing in the bench deposits by the clay content (and, once emplaced, the carbonate content as well) of the sediments. Some (like kangaroo rats and the northern grasshopper mouse) are specifically dryland rodents and can be excluded on that basis alone. Of the fossorial taxa named, the smallmouthed salamander (*Ambystoma texanum*), eastern mole (*Scalopus*

aquaticus), and pocket gopher (*Geomys* sp.) are most likely to live in floodplain habitats, but whether they actually occupied the site itself is unknown. Smallmouthed salamanders are known to occupy abandoned crawdad burrows, but I can find no evidence that they actually dig burrows themselves. The habitat preferences and likely sources of these animals will be discussed in some detail in the chapter on vertebrate remains. Almost all of these animals have extensive horizontal runs. Gophers, for example, have long horizontal runs several centimeters in diameter that lie just beneath the ground surface. As the photos of the unit profiles show, most of the visible disturbances are vertical, there are no large horizontal runs, and most of the vertical traces are probably root stains.

Several lines of evidence can be used to evaluate the extent of bioturbation in the bench deposits: sharpness of stratigraphic contacts, sharpness of chipped stone artifact edges, integrity of bone and shell deposits on buried surfaces, and extent of inversions in radiocarbon assays. Essentially all the stratigraphic contacts are fairly diffuse, indicating that some bioturbation has occurred, probably by plant roots. Charles Frederick noted (see slide 7 notes) that no earthworm turbation was noted in any of the sediment thin sections examined. The upper and lower contacts of the clay-rich strata (2A and 2C) are equally diffuse, which is one of the signals that these strata are not buried soil horizons. No earthworm castings were noted in the excavations or in the small number of sediment thin sections examined. The edges of artifacts from the bench deposits are razor-sharp when examined microscopically. There is no evidence of the kind of microabrasion that can result from burial in extensively bioturbated deposits. The microfauna deposit associated with Feature 5 shows little evidence of disruption. Most of the bone was discovered at the same level as the hearth or slightly higher. The hearth lies at 92.38 m, while most of the microfauna in unit N113 E98 is concentrated at about 92.40 m. Below

that elevation, the amount of bone drops off rapidly; above, smaller quantities of bone were found as high as 92.443 m, the detection elevation for the bone bed in this unit. In other words, while some elements may have been moved as much as 4 cm vertically, most of the bone remained concentrated on a single buried surface.

The mussel shell-bearing surface in stratum 2A shows a similar degree of stratigraphic integrity. Most of the shells found *in situ* or in the unit profiles at this level rested on surfaces between 92.13 and 92.18 m and all were flat-lying; none were rotated into vertical positions. Mussel shells from the same surface seen in the cutbank profile lie at about 92.20 m or slightly above and are similarly flat-lying, although a few were slightly rotated (these cannot be seen very clearly in Fig. 4.22 because of the scale of the drawing, but the orientation is clearly indicated in the original field profile).

My interpretation of the bench deposits is some bioturbation has occurred, and small items have experienced vertical movements up to several centimeters in extent, but bioturbation was arrested as soon as extensive phreatic cementation took place, and as a result, the amount of bioturbation is probably less than that suffered by most archeological sites, especially in comparison to other sites in very slow aggradational settings.

Sediment Thin Sections

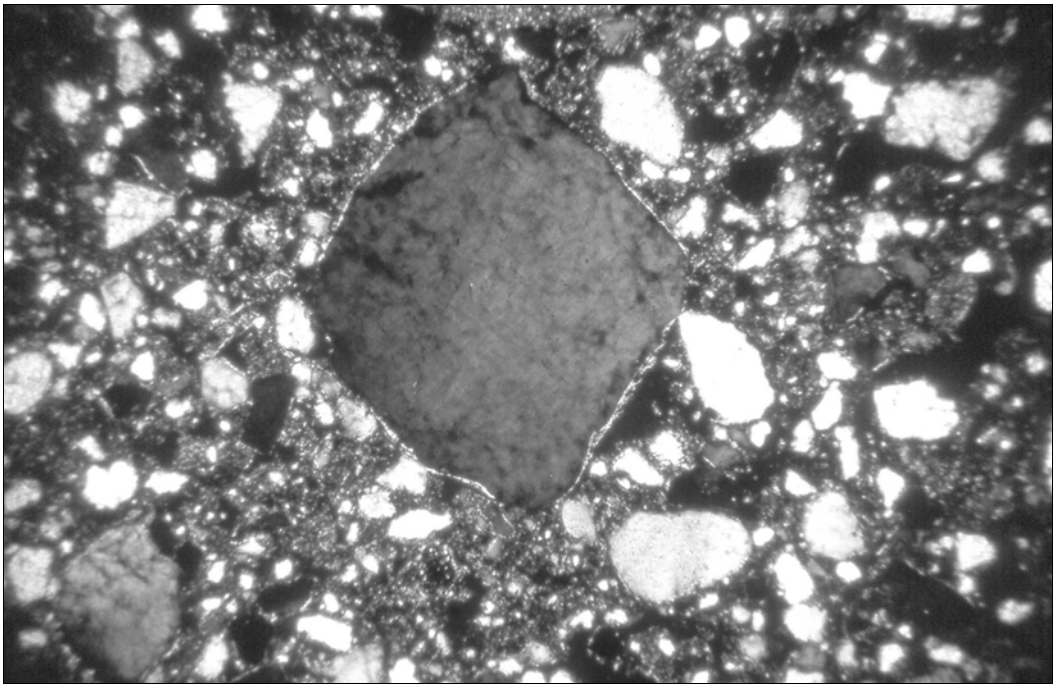
Sediment blocks collected in the field with vertical orientation recorded are useful to check for soil development, since many weathering processes involve vertical translocation of clays and sesquioxides, or vertical cracking during seasonal drying. Because no oriented sediment samples were collected during the original fieldwork, I

selected seven small blocks of sediment with unknown orientation from the matrix samples collected from unit N111 E101 and had them vacuum-epoxied and thin-sectioned by Spectrum Petrographics (Winston, Oregon) in 1995. A potassium ferricyanide stain for highlighting ferrous iron in carbonate-rich samples was also applied to half of each thin section. The thin sections represent strata 1 through 2D and were selected because they were near the middle of the stratum and were thought to typify it, or might represent extremes in grain-size characteristics based on comparison with unit N110 E102. There are one sample each from strata 1, 2B, and 2D, and two samples each from strata 2A and 2C. In early 1996, both Dr. Charles Frederick and I examined the thin sections carefully, and I recorded our observations. Reproduced below are some brief notes on the individual thin sections.

Slide 1 (92.80-92.70 m, stratum 2D): Lithology includes quartz, microcline, zircon, fine-grained chert, chalcedony, plagioclase (?) feldspar. Poorly sorted, not much biosilica, very little detrital carbonate (CF). Many grains have thin surrounding voids that follow the grain surface, where plasma has pulled away from the grain. Clay linings are just as well developed on voids as on grains (KMB). Figure 4.86.

Slide 2 (92.70-92.60 m, stratum 2C): Metamorphic quartz present. Better sorted than slide 1; some detrital calcite present (CF). Figure 4.87.

Figure 4.86 (*following page*). Sediment Thin Section 1. N111 E101 (92.80-92.70 m, stratum 2D). *Top*, large angular grain with argillan on all sides, polarized light. *Bottom*, representative section showing channel, unpolarized light.



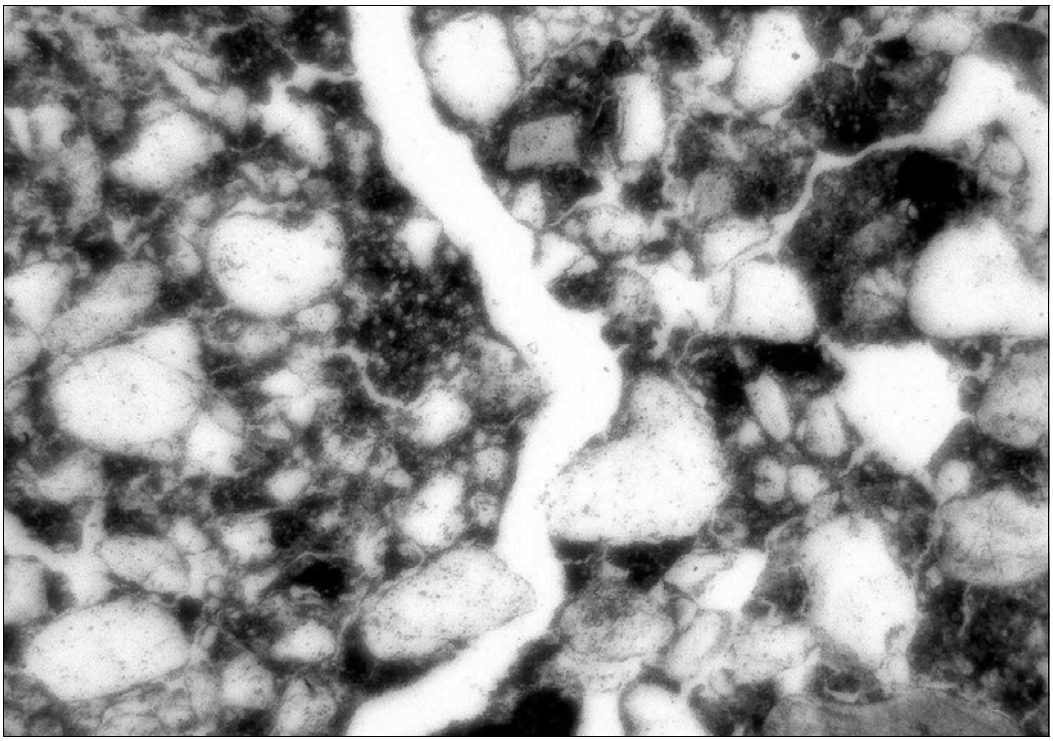
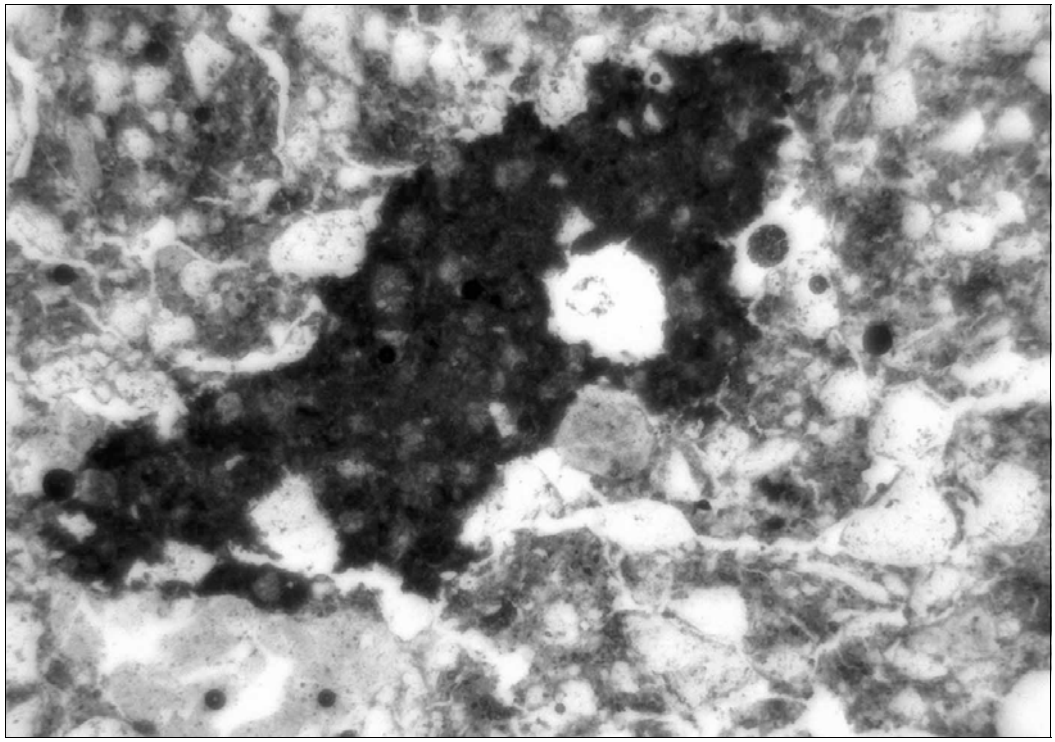
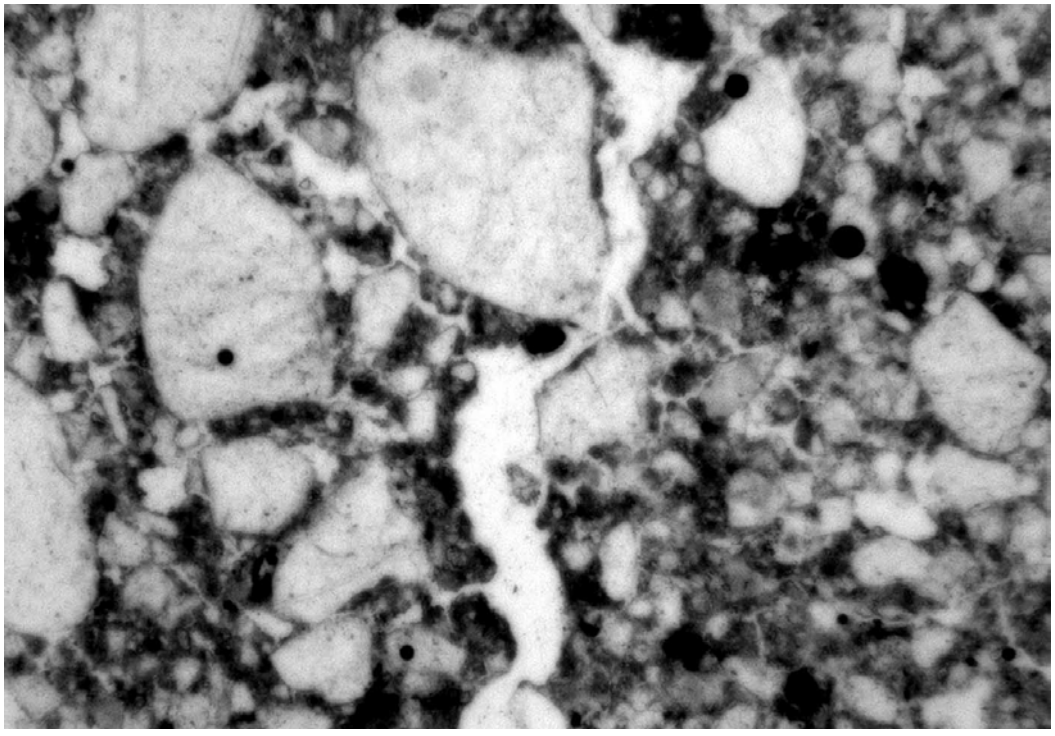


Figure 4.87 (*following page*). Sediment Thin Section 2. N111 E101 (92.70-92.60 m, stratum 2C). *Top*, representative section with red-stained carbonate concentration around small void, unpolarized light. *Bottom*, large sediment grains bearing very faint argillans along fissure, unstained area, unpolarized light. Circular black spots are air bubbles in mounting medium.

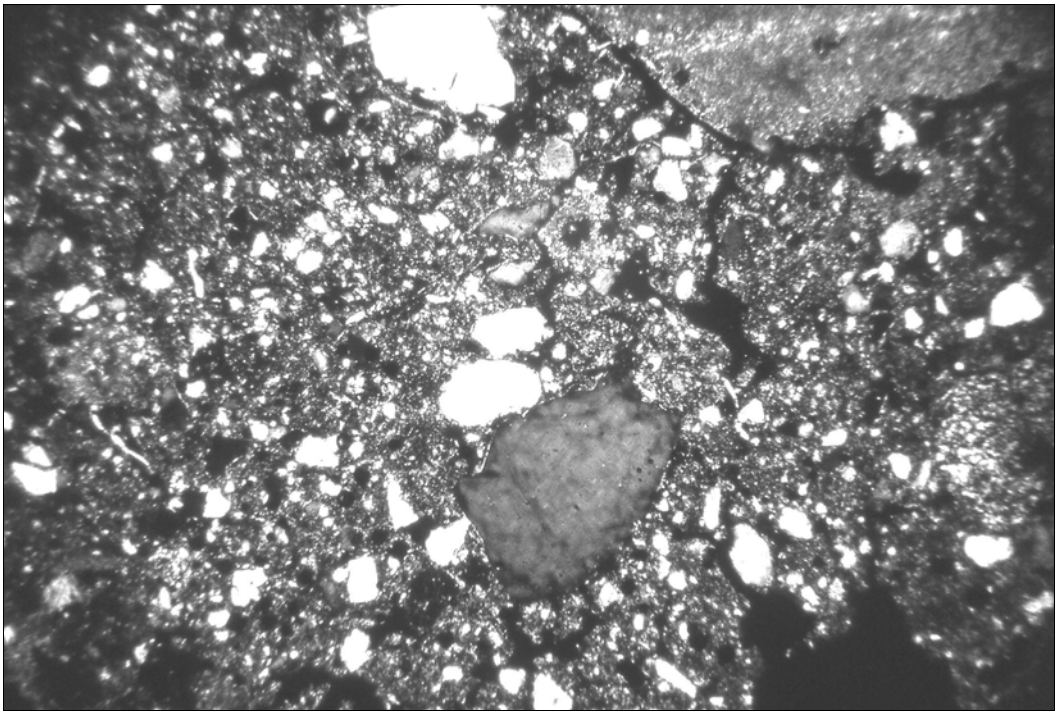




Slide 3 (92.65-92.60 m, stratum 2C): Better sorted than above, finer texture. Very large piece of detrital carbonate present; fair amount of silt. Better structure (more fissures) than slide 1 or 2; better pedality, probably mostly because of finer grain size (CF). This thin section has fewer clasts, more clay, but a few fairly large grains. One grain seen with red-stained lining (KMB). Figure 4.88.

Slide 4 (92.40-92.35 m, stratum 2B): More silt, less clay than above; fine sand. Argillans are small, not common. Lithology about the same as samples above; includes quartz, feldspars (some microcline), some unidentified heavy mineral with heavy relief and unusual cleavage (zircon?). Carbonate approaching nodular form is present (in slides above, carbonate is concentrated around voids). This sample has more snail shell, and a few phytoliths still are present (CF). Faint argillans fairly abundant on large grains, but not necessarily smaller grains; argillans look depositional rather than stress-related. Cross-striated B-fabric not really noticeable except in one area. Fissures mostly lack clay linings. Good example of rhizoconcretion, unidentified amber-colored object, root tubule with phytoliths (?), large fecal pellet (?) with silica coating (?) seen. Biosilica and some possible charcoal were seen (KMB). Figure 4.89.

Figure 4.88. Sediment Thin Section 3 (*following page*). N111 E101 (92.65-92.60 m, stratum 2C). *Top*, representative section, large rock fragment with faint argillan at bottom center in polarized light; clear grains are quartz. *Bottom*, oblong void lined with red-stained carbonate, unpolarized light. Circular black spots are air bubbles in mounting medium.



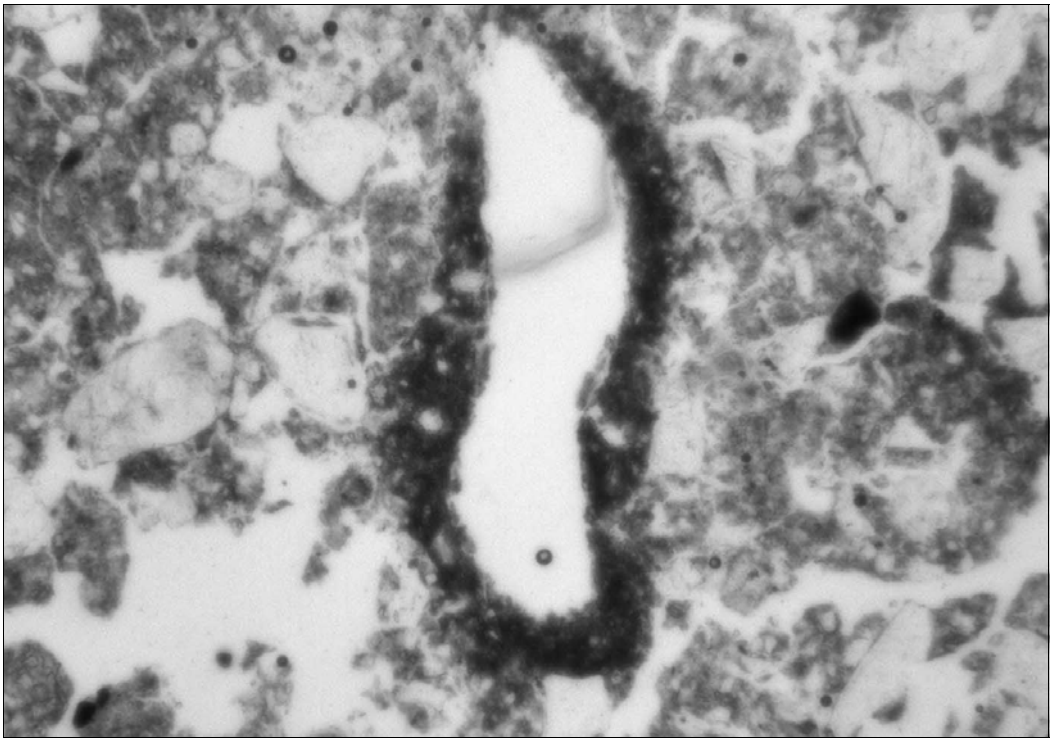
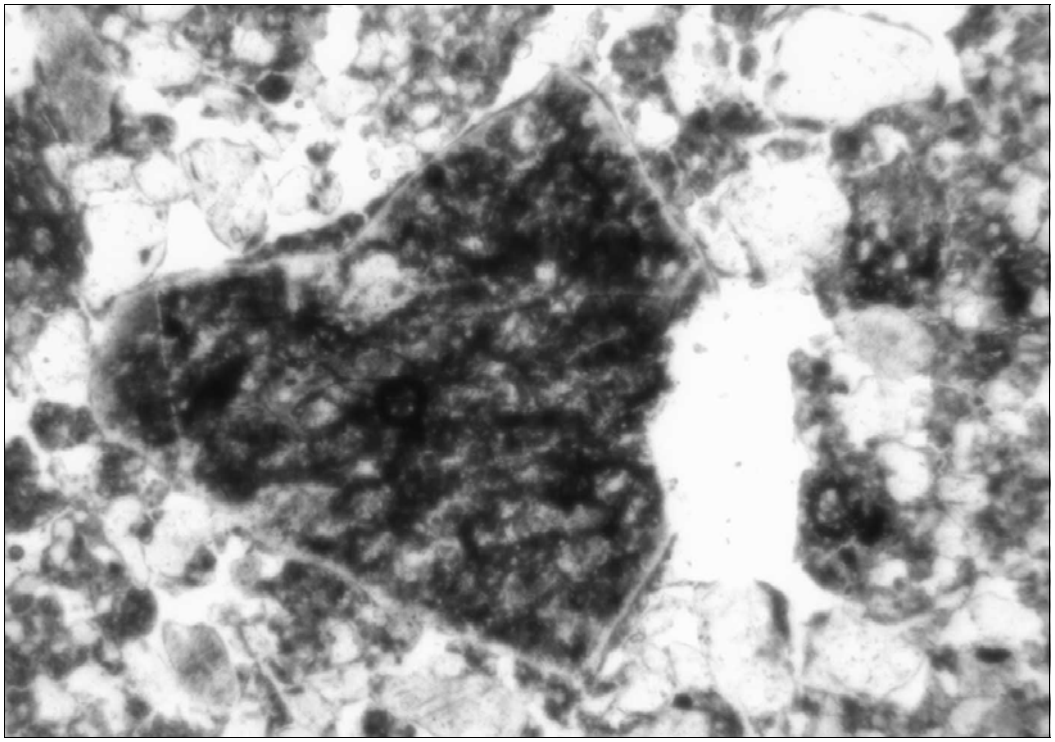
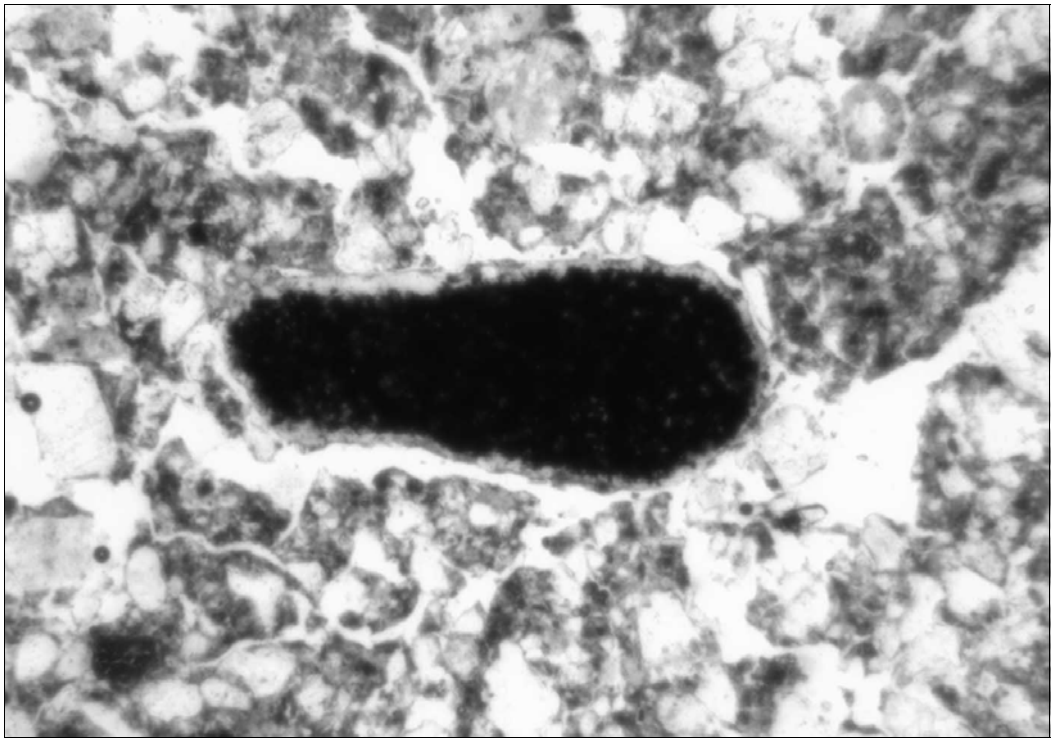


Figure 4.89. Sediment Thin Section 4 (*following page*). N111 E101 (92.40-92.35 m, stratum 2B). *Top*, large angular grain with well-developed argillan, unpolarized light. *Bottom*, possible insect fecal pellet, unpolarized light.





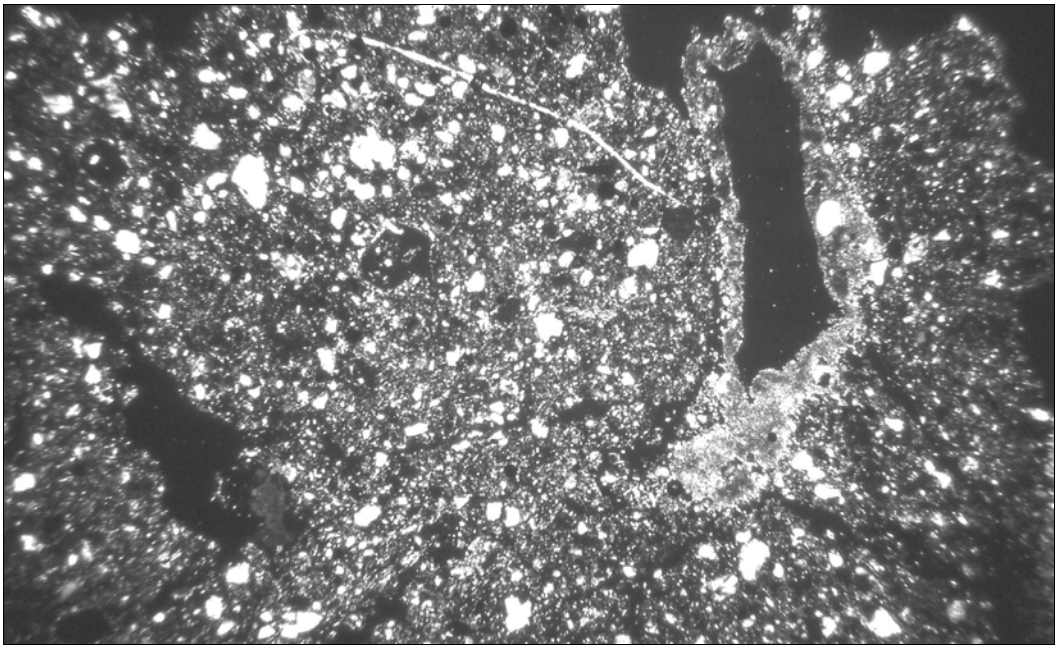
Slide 5 (92.15-92.10 m, stratum 2A): Somewhat more feldspar (though still uncommon) than in previous slides. This sample is better sorted. Rhizolith-like carbonates are better defined. A lot of small biosilica present. Fairly good structure (blocky to subangular blocky). Fair amount of carbonate present. Not many argillans; a few small, thin ones; most clay seems to be in plasma (CF). Circular void with phytoliths and sponge spicules noted. Thin section seems to have a lot of possible phytoliths; sponge spicules also seen. Skeletal grains are mostly very small, few and far apart, so grain counts are low. Argillans are rare and very thin when present; may be stress-related. Not much indication of striated fabric. What appears to be biosilica is very abundant. Clear squarish to rhomboidal objects are much more abundant than sponge spicules. A good many of these presumed phytoliths have faint argillans – more so than the skeleton grains (KMB). Figure 4.90.

Slide 6 (92.05-92.00 m, stratum 2A): Iron/manganese (opaque black-brown spots) fairly abundant. Possible fecal pellet noted. Sorting is poor, worse than slide 5. A lot of carbonate around pores. Massive accumulations of carbonate that may not be pore coats. Two or three different generations of carbonate (see brown mass with gold pore linings inside it). More displacive carbonate growth pushing apart framework grains. Some manganese halos in carbonate around pores. Unidentified mineral (has mahogany-like appearance) seen. More argillans on this slide than slide 5 [note by KMB: this is contradicted by my point counts), mostly around grains rather than channels. Fairly large quartz in fine groundmass (CF). The increased number of faint argillans in this slide may be stress cutans. Most of them are bounded by additional clay and silt, not voids. However, some large grains bounded by voids are definitely depositional. A hint of striation present in plasma. This slide seems to have a lot of finely divided charcoal

(probably associated with Feature 6; charcoal samples were found and collected during excavation in this unit). Charcoal recorded at 12 different coordinate locations. Diatom and sponge spicule fragments seen. Linear void lined with elongated charcoal fragments noted, may be some biosilica associated. Looks like a partially charred organic item later depleted by decay? (KMB).

Slide 7 (91.95-91.90 m, stratum 1): Slightly better sorted than slide 6; more silt. Splotchiness in red-stained area suggests possible secondary mineralization or colloidal silica (?). Some voids have a lining that does not take the stain, and may be silica. Abundant sponge spicules and diatoms. No classic worm turbation in any of the slides. A little bit of FeMn accumulation but not as big or well-developed as in slide 6. Displacive carbonate growth pushing apart skeletal grains and plasma (CF). Slide area is small and highly fissured, and areas with carbonate have few countable grains. This slide has a fair amount of biosilica and very finely divided charcoal toward one side; less charcoal than in slide 6, but still a respectable amount. cluster of charcoal fragments noted at X=39.3, Y=9. Interesting euhedral carbonate growth around skeleton grain noted. Diatoms, sponge spicules seen, some unidentified biosilica. This slide has the most vivid clay interference colors of all seven. Argillans may be stress-related.

Figure 4.90. Sediment Thin Section 5 (*following page*). N111 E101 (92.15-92.10 m, stratum 2A). *Top*, irregular carbonate-lined void to right of center; possible phytoliths are present, but inconspicuous; polarized light. Strawlike object is lint or other contamination on slide. *Bottom*, representative fissured area in upolarized light. Circular black spots are air bubbles in mounting medium.



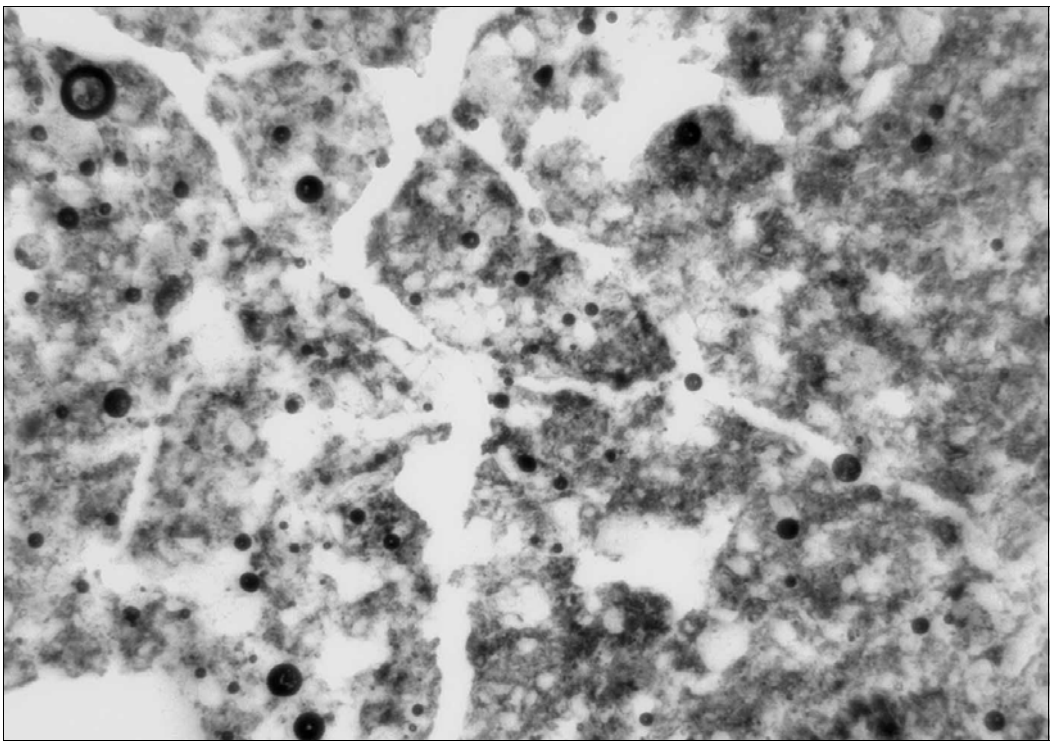
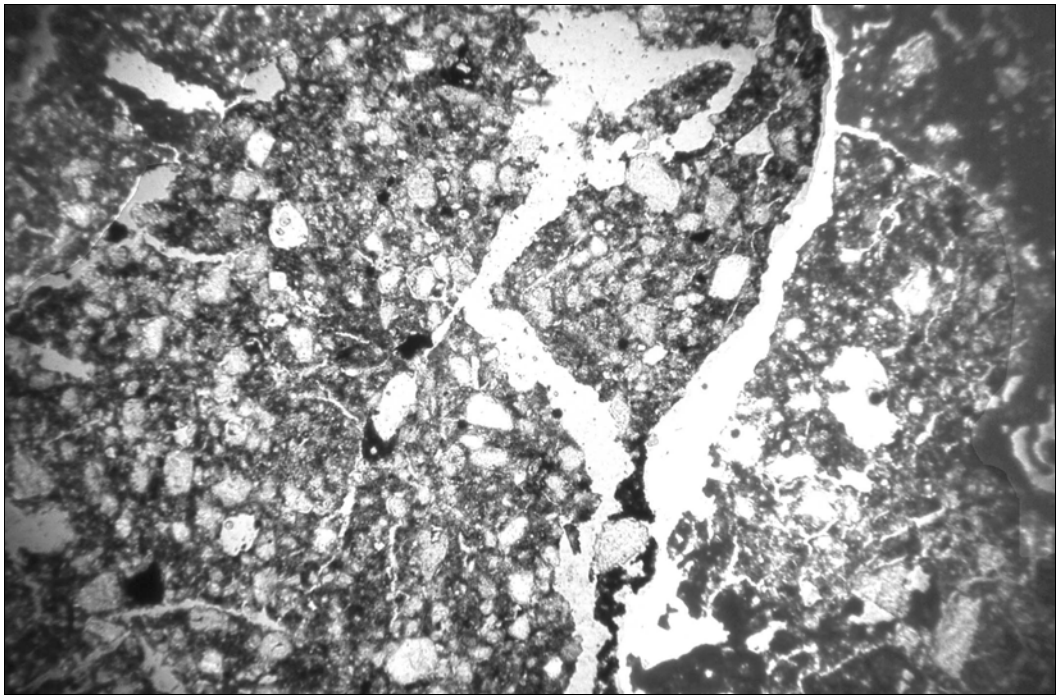


Figure 4.91. Sediment Thin Section 6 (*following page*). N111 E101 (92.05-92.00 m, stratum 2A). *Top*, area showing fissures, charcoal fragments and sponge spicules in unpolarized light. *Bottom*, *Rabdotus* shell fragment in section, carbonate void linings



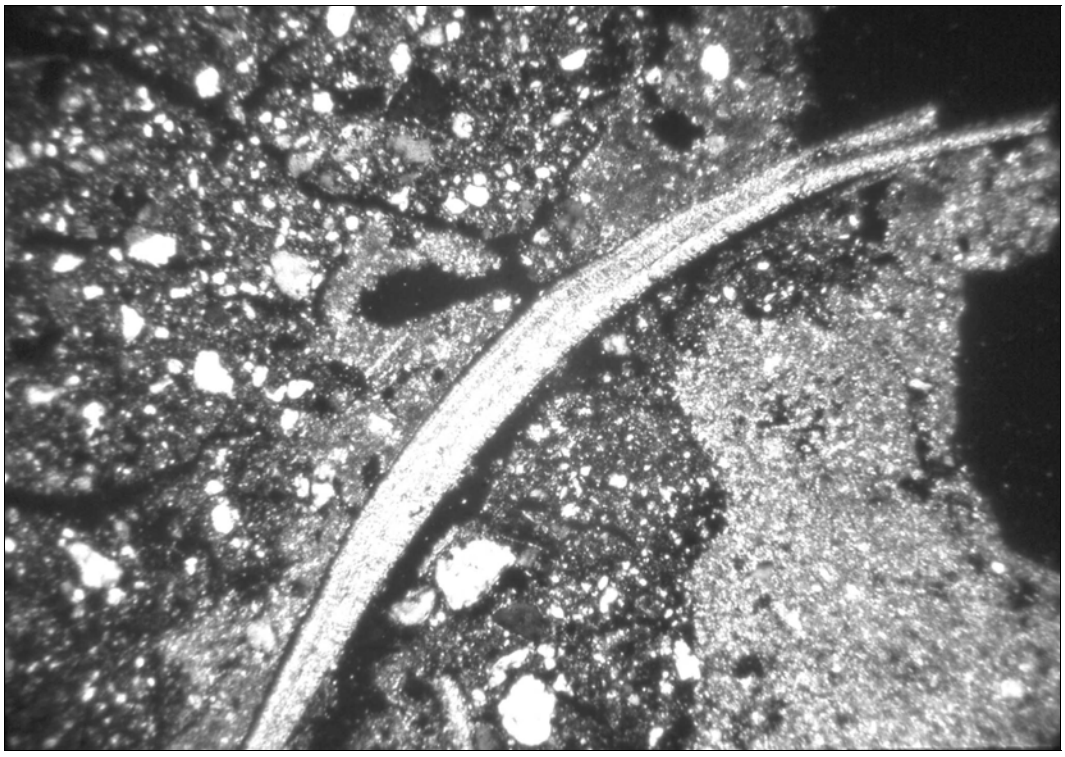
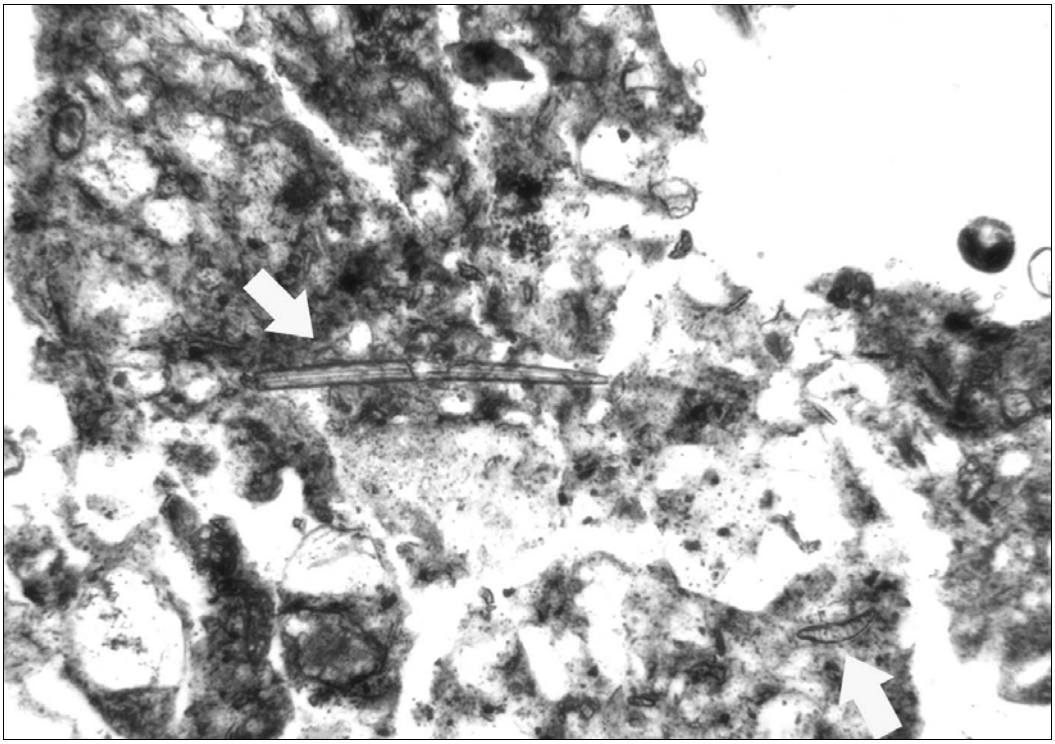
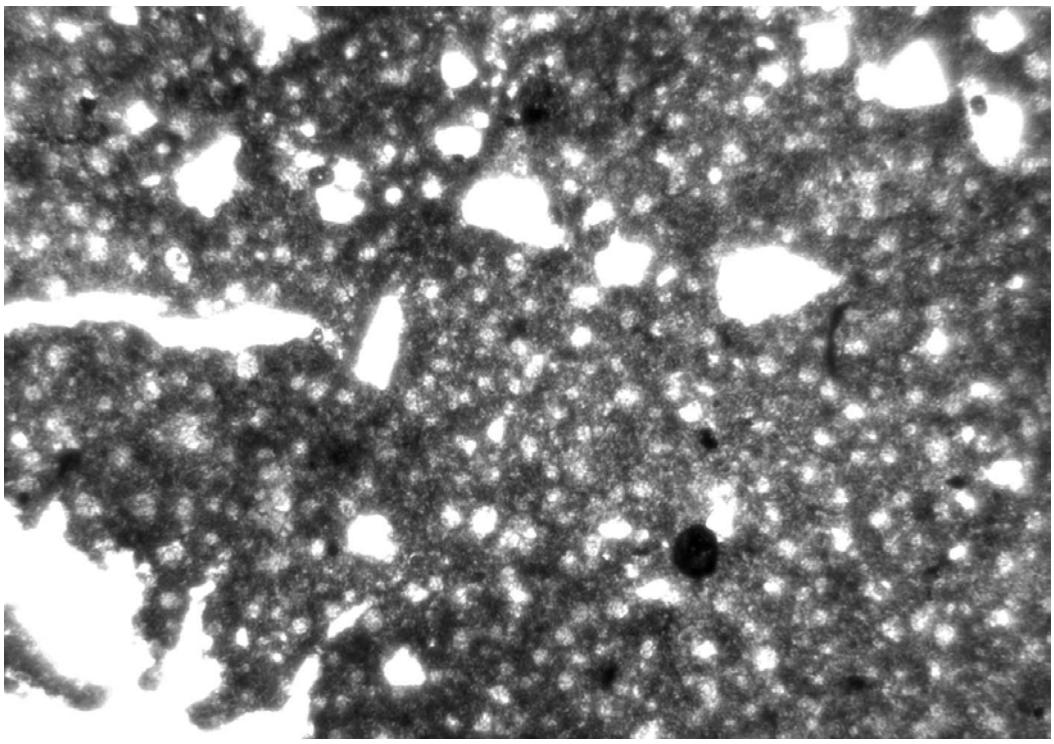


Figure 4.92 (*following page*). Sediment Thin Sections 6 and 7. *Top*, thin section 6 (N111 E101, 92.05-92.00 m, stratum 2A), 10X lens, unpolarized light, showing nearly complete sponge spicule (white arrow near center) and diatom (white arrow in lower right corner). *Bottom*, thin section 7 (N111 E101, 91.95-91.90 m, stratum 1), 2.5X lens, unpolarized light, stained area. Gray mass covering most of view is carbonate; white areas are voids or quartz grains. Dark circular area is an air bubble in the mounting medium.





Despite the fact that the sediment thin sections represent an infinitesimally small sample of each excavated level, they do a remarkably good job of faithfully representing the sediment texture, sorting, carbonate and sesquioxide content documented by larger-scale sampling and analysis methods. Slides 6 and 7 have also faithfully captured the finely divided charcoal associated with the cultural occupation zone around Feature 6, at the base of stratum 2A.

In addition to the essentially anecdotal data collected above, I recorded point counts of argillans on skeleton grains for all seven thin sections. There are several kinds of diagenetic features that could be recorded by point counts, but I chose to concentrate on argillans because these I felt these could be reliably counted and would best whether vertical translocation of sedimentary constituents by vadose water had occurred in addition to groundwater diagenesis. *Argillans* are the microscopic clay films that may accumulate on quartz and other kinds of sediment grains. They can be recognized as bright gold or yellowish linings that extend partway or completely around the circumference of a grain when viewed in thin section with transmitted light.

I placed each slide on a marked X-Y stage with the long axis of the slide running parallel to the X axis, selected 5 different Y coordinates from a random numbers table, and then scanned each of the five transects along the X axis at 50X magnification (or 100X where necessary) under both polarized and unpolarized light. Each sediment grain that was transected by the crosshairs was tallied as “no argillans,” “faint argillans,” or “well-developed argillans.” The number of grains tallied for each slide ranged from 323 to 618, for a total grain count of 3568 for all seven slides. Only argillans on skeleton grains were counted; argillans on pores, channels, and biosilica were not counted, despite

the fact that clay linings on pores and phytoliths are fairly common at some levels. Depositional and stress argillans were not distinguished in the counts. *Stress argillans* are created when seasonal expansion and contraction of clay-rich sediments realigns clay platelets next to sediment grains. They represent localized realignment of clay, rather than actual movement of clay into a horizon from overlying zones.

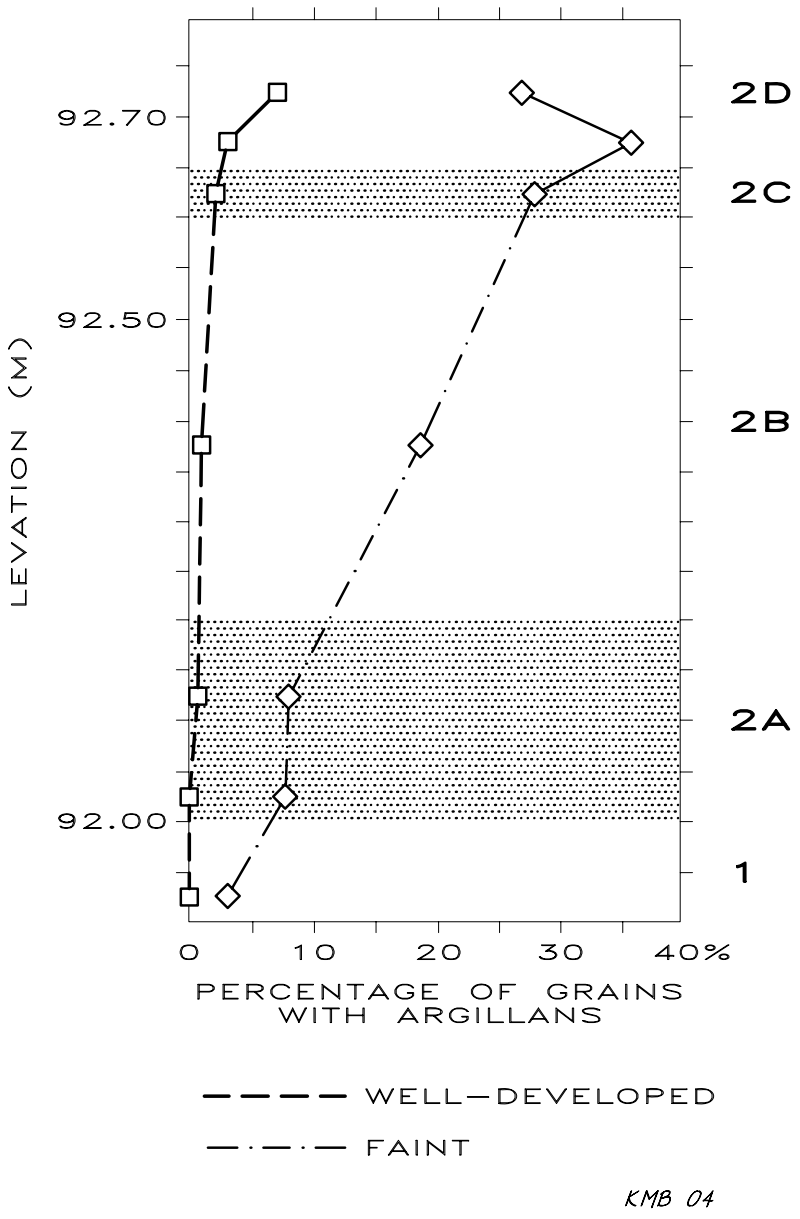
The results of the point counts are shown in Table 4.13 and Figure 4.93. The point counts show the majority of the sediment grains lack clay films entirely, and when they are present, they are usually not well-developed (the lowest two slides lack them entirely). This suggests that downward translocation of clay by vadose water was a relatively uncommon weathering process in the history of the bench sediments, and it helps to confirm that the clay-rich strata do not represent translocated clay. Translocation of clays is inhibited by flocculation, which is promoted when carbonate and iron hydroxides are present (Birkeland 1984:132-133), as is the case in the bench sediments. Figure 4.93 also shows that argillans become increasingly scarce with greater depth in the profile, and do not increase in the clay-rich strata (shaded in the illustration). The only significant development of argillans is at the top of the profile, probably for two reasons: 1) groundwater saturation in the basal part of the profile has excluded clay translocation, 2) the bench sediments were exposed to more intense weathering later in the bench stratigraphic sequence, when the uppermost strata were accumulating.

Table 4.13. Point Count Data for Argillans on Skeleton Grains (Selected Samples from N111 E101).

Excavation level (m)	Stratum	No argillans present (%)	Faint argillans (%)	Well-developed argillans (%)	Number of grains counted
92.80-92.70	lower 2D	66.25	26.78	6.95	489
92.70-92.65	upper 2C	61.39	35.65	2.95	575
92.65-92.60	mid-2C	70.17	27.89	1.93	466
92.40-92.35	mid-2B	80.53	18.62	0.84	714
92.15-92.10	upper 2A	81.33	8.04	0.61	323
92.05-92.00	lower 2A	92.23	7.76	0.00	618
91.95-91.90	upper 1	96.86	3.13	0.00	383
TOTAL:					3568

NOTES: Samples are unoriented; counts are for argillans on skeletal grains only; argillans on pores, channels, and biosilica were not counted (clay linings on pores are fairly abundant at some levels). Counts at 50X (and where necessary, 100X) under unpolarized and polarized light, along four randomly selected X-transects per slide (five transects for the 91.95-91.90 sample). Depositional and stress argillans were not distinguished in the counts; most of the "faint argillans" in the lowest three samples may actually be granostriated birefringence fabric.

Figure 4.93 (*following page*). N111 E101, Percentage of Grains With Argillans. Plotted here are point count data for seven un-oriented sediment thin sections from the N111 E101 matrix sample column. Four transects were done for each slide, and the percentage of sediment grains bearing argillans (clay coatings) was tallied, each instance classified as "well-developed," "faint," or "none." Counts are for argillans on skeletal grains only (a total of 3568 grains was counted for all seven slides); argillans on pores, channels, and biosilica were not counted. Note that argillans are scarce but are most frequent at the top of the column, and are not markedly more abundant in the muddy zones.


92.70
92.50
92.00
LEVATION (M)
2D
2C
2B
2A
1
0
10
20
30
40%
PERCENTAGE OF GRAINS WITH ARGILLANS
WELL-DEVELOPED
FAINT
KMB 04

INTERPRETING THE DEPOSITIONAL AND DIAGENETIC RECORD

Evidence for a Nearby Spring

Reconstructing the former environment of an archeological site from the remote past can be difficult when the terrain (relative elevation above a stream channel), climate, groundwater discharge rates, stream morphology and plant life have all changed and can only be inferred generally. Cold spring sites in the eastern US are usually characterized by complex interlayers of sand, gravel, clay, and "organic sand" or peat, often in lenses convoluted or contorted by soft sediment deformation. The few spring sites documented in the literature seem to be mostly paleontological localities where megafauna have been recovered. Good examples are found in Missouri (Haynes 1985:Figs. 9, 15, 17, 18; Saunders 1977:Fig. 5-7, 16), Nebraska (Adair 1989:Figs. 9, 13, 18, 21, 22-24, 27, 30), Nevada (De Narvaez 1995) and in Texas at the Aubrey site (Ferring 2001:Fig. 3.17 and 41-42). In most cases these seem to be artesian springs with an associated funnel-shaped conduit where spring discharge emerges under pressure. The conduit may have a basal gravel overlain by contorted deposits of well-rounded and polished sands; "in general, springs are characterized by a complex microstratigraphy of interbedded clastic, carbonate, and carbonaceous sediments overlying conduits fill with well-sorted sand and gravel" (Waters 1992:216). Haynes (1985:16-20) provides a good analysis of spring development. The peat deposits are accumulations of hydrophilic vegetation in ponds or marshy areas hosted by topographic lows.

Spring sites in the Plains, Great Basin and Southwest lack peat deposits but may be marked by organic "black mats" (De Narvaez 1995, Quade *et al*. 1998) that formed

during the Younger Dryas. These may be seeps or gravity springs feeding cienegas or playas, or they may be artesian springs associated with rock faults. Many of the western sites in carbonate rich regions have extensive deposits of marl, tufa or travertine (Haynes 1967; Nelson *et al*. 2001; Newton and Grossman 1988; Kaufman *et al*. 2002; Pigati *et al*. 2004), sometimes elevated well above modern water tables. Marshy or damp-ground snails, such as the genera *Catinella* or *Oxyloma* of the family Succineidae may be common. Many of the spring sites in the eastern US are still active, but the western sites are often fossil sites documenting higher groundwater recharge and discharge rates during the Younger Dryas or earlier periods (Quade and Pratt 1989). The Hajny Mammoth Site is a good example of a Plains spring site with well-defined conduits (Wyckoff 1992:Figs. 5-7, 5-11, 5-14, 5-15 to 5-17) but no organic deposits. Regarding springs associated with fine-grained deposits in the Great Basin, Quade and others observe that "Most carbonate cements develop along a capillary fringe in the subsurface, due probably to pumping by phreatophytes, thus driving solutions toward supersaturation with respect to calcite" (Quade *et al*. 1995:218) and that seems to apply to the bench deposits at Berger Bluff as well.

There is no direct evidence for a spring conduit, pool, or spring run visible in the bench deposits at Berger Bluff. Likewise, there is no evidence of ponded water in the immediate bench area, nor were any clear examples of travertine or tufa found (although much of the fossil wood superficially resembles travertine). There are no peat deposits, nor any indication that peat deposits were once present but later destroyed by oxidation.

Despite this lack of direct evidence, I believe that the bench area represents the margin of a former spring or seep, probably associated with the ravine located

immediately upstream, with a small Goliad sandstone outcrop serving as the aquifer. The evidence for this spring consists of 1) the extensive subsurface deposits of phreatic carbonate and extensive accumulation of carbonate in the form of rhizoliths, 2) the presence of a contemporary spring pool nearby in the ravine before reservoir inundation (Fig. 1.31), and 3) the occasional presence of cold spring snails (*Valvata tricarinata*) in the bench deposits. The phreatic carbonate deposits appear to be somewhat localized, indicating that they were not part of the stratigraphy throughout the entire floodplain, and it could well be that spring discharge has been fixed in this spot for much of the Quaternary due to the location of the Goliad Formation outcrop and perhaps even because of minor faulting (?) along the axis of the ravine (although that is speculative, and not based on any physical evidence). There is no direct evidence bearing on the presence or absence of a spring pool, but I think it is likely a pool or spring run was present somewhere, serving as the principal attraction for human occupants of the site. The absence of peat or other extensive organic deposits may be due to the lack of a suitable topographic depression in the bench area.

The extent to which the bench deposits were damp or groundwater-saturated as they accumulated can be assessed from the diagenetic record and the inventory of snails and diatoms (the two kinds of organisms most likely to have lived directly on the site). Carbonate and sesquioxide accumulation, ferromanganese concretions, and evidence of structure (fissuring) and argillans seen in the thin sections all indicate that the sediments were damp much of the time but were also seasonally desiccated. Oxidation of iron, micromorphological evidence of fissuring, and limited development of argillans, especially in the upper part of the section, suggest significant seasonal drying. This is

somewhat surprising, given the evidence presented in Chapter 1 for restricted seasonality at the end of the Pleistocene.

Depending on the size of the snail and the recovery method used, about 96-99 % of the snails from the bench deposits are terrestrial taxa. This proportion of terrestrial species is quite typical for stream-terrace archeological sites in Texas, even when the terrace surface is close to and not far above the channel. Large numbers of aquatic or damp-ground taxa are rarely found in archeological sites unless a depression or washover of some sort is present on or near the site. In the bench deposits, the largest number of aquatic taxa are found toward the bottom of the section in upper stratum 1, stratum 2A, and lower stratum 2B. Aquatic taxa represent a very small proportion of the large and medium-bodied snails but a somewhat larger proportion of the microsnails. Damp ground taxa such as *Catinella vermeta*, *Pupisoma disocoricola*, *Pomatiopsis lapidaria*, or *Carychium mexicanum* and aquatic taxa such as *Cincinnatia integra*, *Gyraulus parvus*, *Biomphalaria havanensis*, or *Valvata tricarinata* are found in small numbers among the microsnails. Similar taxa (at the generic level) are found in the black mats from Nevada reported by Quade *et al*. (1998:Table 2), but in much larger numbers. The black mats also tend to lack the larger numbers of terrestrial taxa found in the bench. The terrestrial taxa from the bench are a mixture of drought-tolerant and more moisture-dependant woodland taxa.

Many diatom taxa were recovered from the bench deposits. Nearly all are characteristic of marshy or aquatic habitats. The counts, however, are dominated by a much smaller number of taxa that occur in greater abundance than the others, which are represented by only a few specimens. One abundant taxon, *Hantzschia amphioxys*, is a

soil diatom. The other major taxa (such as *Pinnularia borealis*, *Navicula mutica*, *Epithemia turgida, E. adnata*, *Fragilaria ulna*, *Cocconeis placentula*, and *Nitzschia amphibia*) are variously characteristic of soil, marshy, and aquatic habitats. There is a clear pattern of declining species richness and abundance over time and toward the top of the section, especially above stratum 2A, probably as a result of increasingly frequent and pronounced seasonal drying as the Younger Dryas ended and the Holocene began. Many of the species are alkaliphile, which is not surprising given the calcareous nature of the aquifer. There are a couple of species, such as *Diploneis petersenii* and *Diadesmis aerophila*, that are characteristic of peat or other mossy microhabitats, but they are scarce. The soil and marsh diatoms probably represent populations growing on the site, while the smaller number of aquatic forms represent diatoms that originated in Coleto Creek and were deposited by flooding. Both snails and diatoms will be discussed in much greater detail in the chapters on biological remains.

Cyclic Bedding

Apart from cementation, the most striking characteristic of the bench deposits is the apparent occurrence of *cyclic bedding*. There appears to be a regular alternation of sandy and muddy units that can be arranged in pairs or couplets. Strata 1 and 2A are relatively thick and distinct, 2B and 2C are thinner and less distinct, 2D and 3 somewhat thicker again. Unfortunately, the sequence is not long enough to be certain that a true A-B cycle is present, but the pattern is still distinctive enough to require explanation.

Five explanatory hypotheses seem possible. The first two can be discarded fairly easily, but the other three require more detailed consideration.

Hypothesis 1 (Buried Soils): The dark bands visible in the cutbank superficially resemble buried soils. The same thing has been observed for the "Modern alluvium" on the Concho and North Concho River (Frederick 1996:99). The dark bands are clearly not buried A horizons, as the organic content is far too low (about 0.1% of the silt-clay extract used for radiocarbon assay), and the dark color is derived chiefly from the clay and silt content. The possibility that these are Bt horizons can also be ruled out. Birkeland (1984:Table 2-1) gives some very specific criteria for recognizing an argillic horizon. It must be at least 7.5 or 15 cm thick, depending on texture and thickness of overlying horizons; it must have at least 120% of the amount of clay in the overlying horizon (in cases where these horizons have 15-40% clay), and clay bridges or cutans must be visible in thin section. Depending on the clay mineral, translocation ceases when the clay percentages rises above 20-40%, since the clay essentially clogs the porosity of the soil (Birkeland 1984:134). Clay proportions range from about 8% to over 45% in the sediment sample column. In cases where a complete, uneroded solum is present, most buried soils have a sharp upper boundary and a diffuse lower boundary (Brakenridge 1988:151, Retallack 1988:7). Well-developed argillic horizons usually show a "clay bulge" in which most of the clay occurs at the top of the horizon, and tapers off below that (Birkeland 1984:126; for an example see Ferring 1992:Fig. 1-9), but strata 2A and 2C do not fit the pattern very well. Clay and silt increase from top to bottom in stratum 2C and are increased, but more or less constant from top to bottom in stratum 2A (Fig. 4.65). Another consideration is that for both strata, the thickness of overlying sandy sediment is probably insufficient to generate the amount of clay concentrated in these muddy units (about 40 cm of sand over stratum 2C and 55-70 cm over stratum 2A). The "clay bulge" for each of these zones is thinner, more compressed, and abrupt than would be expected for a horizon of pedogenic origin. The thin section data show that argillans are present, but they are uncommon,

poorly developed, and diminish steadily from the top to the bottom of the section. Most significantly, they do not increase in the clay-rich horizons (Fig. 4.93). The source of the clay expressed as argillans is unknown; possibly all of it is derived from stratum 3. Soil scientists estimate that at a span of least 2000-3500 years is required for development of an argillic horizon (depending on parent material and climate; Cremeens 1995:1383), while the couplets seen in the bench deposits probably represent roughly a millennium.

My interpretation of the muddy strata is that they represent depositional, not pedogenic features, and although there has been some limited translocation of silt and clay, it was largely discouraged by frequent high water tables and high carbonate content of the sediment until late in the history of bench aggradation. The "buried soil" hypothesis can be rejected.

Hypothesis 2 (Graded Point Bar Bedding): According to the classical model of Wolman and Leopold (1957) based on their study of Watts Branch in Maryland, floodplains occupied by meandering streams are formed chiefly by lateral accretion. According to this model, the coarsest-grained material remains in the channel bed where stream power is greatest; finer grained material accumulates in point bars, and the "decrease in flow velocity upwards across the bar surface results in the deposition of coarser particles at the base and finer particles at the top of the point bar. The decrease in grain size upward is referred to as a fining-upward sequence… This sequence of lateral accretion sediment is capped by vertical accretion deposits, usually thin, horizontally laminated silts and clays washed over the bar surface during overbank floods" (Waters 1992:133; see also Allen 1965:140). Lateral accretion deposits, then, are a series of onlapping layers that might include gravel at the base, sand in the middle, and a *topstratum* of silt and clay (Frazier and Osanik 1961:Fig. 2; Bernard *et al*. 1970:Fig. 23; Morton and McGowen 1980:Figs.

17, 18; Saucier 1994:192). As the channel marches from side to side across the valley width, a continual layer of coarse sediment is laid down at the channel base and a continual fine-grained topstratum is laid down at the surface. Incidentally, contemporary Coleto Creek side-attached and point bars are stratified with respect to sedimentary structures (Morton and McGowen 1980:Figs. 29-32), but are almost exclusively clean sand. As Collins (1995:367-368) has pointed out, the absence of archeological sites on the concave sides of meanders is due to lateral migration.

The hypothesis that each couplet in the Berger Bluff stratigraphic sequence represents a graded point bar deposit can easily be rejected. There is no evidence that the Coleto Creek channel has migrated across the bench area (at least since the valley was previously incised earlier in the Pleistocene), and there are no channel lag deposits or unconformities visible anywhere in the cutbank or excavations. There are also a number of buried cultural and noncultural features that would have been removed if the creek channel had migrated across the area during the period of concern. All of the floodplain deposits making up the bench were clearly deposited outside the creek channel, not in it. furthermore, if each of the three or so couplets represented a single fining-upward flood event, an extraordinarily long recurrence interval would be implied to account for the 2000-2500 or so years of deposition that is probably present.

Since the influential work of Wolman and Leopold on Watts Branch in the 1950s, a great deal more global research on floodplain construction has been done, and it is now known that, contrary to the classical model, many floodplains are actually built by vertical accretion. Some examples are given by Schumm and Lichty (1963), Ritter, Kinsey and Kauffman (1973), Stene (1980), Nanson and Young (1981), Hereford (1984),

Nanson (1986), Gomez *et al*. (1998), Allred and Schmidt (1999), Moody, Pizzuto and Meade (1999), and Moody and Troutman (2000). These are examples of class C1 floodplains as defined by Nanson and Croke (1992:477-478). Floodbasins of large fine-grained rivers may have tens of meters of vertically accreted overbank sediments. Farrell (1987) reports 10 meters of floodbasin sediments for the Mississippi River near Baton Rouge. Collins (1999) reports about 1.5 m of sandy vertical accretion sediments, apparently representing a very small number of historic flood events on the right bank of Smith Creek, across from the Smith Creek Bridge site. This and the examples given by Schumm and Lichty show that vertical accretion can sometimes be quite rapid. Vertical accretion can occur in either the floodbasin or the channel (in which case channel narrowing occurs). In addition to these geological examples, there are many archeological examples of occupation sites encased in thick sequences of fine-grained alluvium that have never been disrupted by channel migration. In Texas, the Devil's Mouth site (at least 15 m of overbank or eolian sediments; Johnson 1964, Sorrow 1968a:Fig. 13), Nopal Terrace (at least 5.5 m; Sorrow 1968b), 41 LK 31/32 (up to 15 m; Scott 1982:16) and the Richard Been site (about 20 m; Thoms 1992) are good examples. Sites like these persist either because the river channel is laterally stable, or never migrates all the way from one side of the valley to the other, and is able fill the floodbasin with thick sequences of overbank sediments, contrary to the classical Wolman-Leopold model. These "*gisements*" are testament to the potential importance of vertical accretion deposits. In some cases, the asymmetrical positioning of tributaries on only one side of a main valley may dump sediment preferentially on one side of the valley, protecting that part of the valley fill from lateral migration.

Hypothesis 3 (Graded Floodbasin Bedding): According to Allen (1965:153),

> Interstratification of coarse with fine overbank sediment is found throughout the topstratum of floodplains lacking clear environmental subdivisions. Flood waters are not obstructed in their passage down these plains devoid of significant relief, in contrast to the situation in floodplains marked by alluvial ridge-floodbasin complexes that impede and pond flows. In the latter floodplains interstratification of coarse with fine layers is generally limited to levees. …units varying in thickness from a fraction of an inch to a foot or so are involved. In certain cases it is the coarser units that are dominant, in others it is the finer layers…. The deposit of each flood usually comprises a coarse layer below representing the rise to maximum stage, followed gradationally by a fine unit recording recession.

Allen refers to these as "undivided topstratum deposits" (see Allen 1965:Fig. 31). This hypothesis has a measure of plausibility, but inherits the same objection as hypothesis 2 –the span of time represented by the bench deposits is probably too long to be accounted for by only three flood couplets. Furthermore, some of the cultural and noncultural features are found buried in the middle of the coarse or fine units.

Some archeological sites with alternating silty and sandy zones may be examples of this kind of bedding, although the origin of the bedding is rarely discussed explicitly. The Devil's Mouth site might be a possible example. At the Turkey Bend Ranch site, banding is interpreted as out-of-phase sediment contributions from the Concho River and Colorado River (Treece *et al*. 1993:Fig. 5.5; Lintz, Treece and Oglesby 1995:157). Research by Moody. Pizzuto and Meade (1999:Fig. 8) shows that multiple sandy and muddy units can occur in a single annual flood deposit.

Hypothesis 4 (Autocyclic Bedding): According to this hypothesis, sandy and muddy units simply represent different facies of floodplain sediment deposition. Sandy units were deposited when the laterally migrating creek was near the site (but without actually removing any of the bench sediments) and muddy units were deposited when it was

distant. The caliber of the sediment represents the proximity of the energy source responsible for transportation. This model, termed *autocyclic bedding* (Beerbower 1964), simply implies redistribution of energy within the depositional system, but no net change in energy input into the system as a whole.

During overbank flooding, deposition rates are highest at the channel banks and drop off exponentially toward the flood basin (Walling, Quine, and He 1992:Figs. 7.5, 7.8; Walling and He 1998:Fig. 3; Törnqvist and Bridge 2002:Figs. 2, 6, 7) because current velocity drops off rapidly once the overbank environment is entered and is no longer able to sustain sediment particles in traction or saltation. In part, this is because current velocity is slower at the top of the water column, and in part because the channel bank is often vegetated and vegetation breaks up laminar flow and creates turbulence, allowing sediment to drop out of suspension. It is this energy decay process that accounts for the presence of levees bordering the channel. However, once levees are in place, it is possible for some of the highest rates of deposition to occur in floodbasin depressions. this is particularly true for fine-grained systems with heavily vegetated floodplains like the Cache River reach studied by Kleiss (1996). She documented accretion rates in the cypress-tupelo swamp equal to or greater than that on the levee systems (Kleiss 1996:330) and estimated that about 14% of the suspended load entering the bottomland hardwood forest is retained there annually.

Sediment grain size also drops off exponentially away from the channel in most cases. Table 4.14 lists a few actualistic case studies (arranged very roughly by increasing catchment or stream size) showing how overbank sediment becomes progressively finer away from the channel. These studies are based either on samples collected in transects

run at right angles to the channel axis, or sometimes on grids of sampling mats. Surface samples, cores, or sometimes sediment traps made of artificial turf are used. Grain size is usually reported as median grain diameter or as a percentage of various size grades (sand, silt, clay). Walling, Owens and Leeks (1997:Fig. 11) have recompiled a few of these grain size decay curves in terms of percentage distance from the channel. In most cases, grain size drops off dramatically within about the first 20% of the total transect length and then varies little beyond that. In a few other cases, the decay function is much flatter, possibly indicating the absence of floodplain vegetation, or strong convective currents that penetrate the interior of the flood basin for some reason. Figure 4.94 shows some examples of grain size decay curves from streams of differing scales in England, Wales, and Australia. Figure 4.95 shows relative amounts of clay, silt, and sand in three different transects running away from the channel of the River Severn in England (after Marriott 1996:Fig. 3.5). The samples are mostly silt, but note that clay is present all across the floodbasin, while large amounts of sand are confined to the channel margin.

Exponential decay of grain size means that in most cases, the flood basin area beyond the "levee" region immediately adjacent to the channel is covered with silt and clay deposits that are fairly uniform in size. In effect, the decay curve resembles a two-state system: flood basin deposits are fine-grained until a channel moves very near through lateral migration (or in some cases until levee progradation occurs), at which point the overbank deposits become abruptly coarser-grained.

Table 4.14. Case Studies of Sediment Fining Away from Channels.

1. Hughes and Lewin (1982:Fig. 3, C), Nameless artificial channel, Wales
Catchment size: ?
Channel width: 1.11 m
Floodplain width: 8.8 m
Transect length: 5 m
Data: median diameter

2. Nanson and Young (1981:Figs. 5, 6), American Creek and Minnamurra River, Australia
Catchment size: 27 km^2, 142 km^2
Channel width: ?
Floodplain width: ?
Transect length: 45 m, 80 m
Data: % silt and clay

3. Lecce and Pavlowsky (2004:Figs. 5, 6), Blue River, Wisconsin
Catchment size: 2.0-128 km^2
Channel width: ?
Floodplain width: 60-360 m (valley width)
Transect length: 14-140 m
Data: % sand

4. Walling, He and Nicholas (1996:Fig. 12.14), River Culm, England
Catchment size: 276 km^2
Channel width: ?
Floodplain width: ?
Transect length: 120 m
Data: % finer than 0.063 nm

5. He and Walling (1998:Figs. 4, 7), Rivers Stour, Culm, Severn, Rother, Avon, England
Catchment size: 276, 355, 523, 2900, 3717 km^2
Channel width: ?
Floodplain width: ?
Transect length: 140-300 m, 90-300 m
Data: % clay, % sand, median diameter

6. Cazanacli and Smith (1998:Figs. 6, 7), Saskatchewan River, Centre Angling Channel, Saskatchewan
Catchment size: ?
Channel width: (estimated at 80-240 m based on Fig. 2)
Floodplain width: ?
Transect length: 40-120 m
Data: %fine sand, % very fine sand, % coarse silt, etc. to clay, median diameter

(continued on next page)

7. Wistendahl (1958:Fig. 2), Raritan River, New Jersey
Catchment size: ?
Channel width: ?
Floodplain width: less than 0.5 mi
Transect length: 170 m
Data: % sand, % silt, % clay

8. Walling, Owens and Leeks (1997:Figs. 4, 11), Rivers Wharfe and Ouse, England
Catchment size: 818 km^2 and 3315 km^2
Channel width: ?
Floodplain width: ?
Transect length: 140-200 m
Data: median diameter

9. Marriott (1996:Figs. 3.4, 3.5), River Severn, England
Catchment size: 10,000 km^2
Channel width: 60-70 m
Floodplain width: ca. 360-575 m (?)
Transect length: ca. 250-650 m (?)
Data: mean grain size in phi units; % sand, silt, and clay

9. Hudson and Heitmuller (2003:Fig. 8), Pánuco River, Mexico
Catchment size: 98,227 km^2
Channel width: ?
Floodplain width: ca. 2-20 km
Transect length: 1 km
Data: median grain size as D_{84} mm

11. Asselman and Middlekoop (1995:Fig. 10, 12), Rivers Waal and Meuse, Netherlands
Catchment size: 250,000 km^2 and 33,000 km^2
Channel width: 260 m and 150 m
Floodplain width: ?
Transect length: 300 m
Data: % sand

12. Guccione (1993:Figs. 6-8), Buffalo, White, and Mississippi River, Arkansas
Catchment size: ?
Channel width: 20 m, 30 m, 1600 m
Floodplain width: 0.3 km, 2.1 km, 88. 5 km
Transect lengths: 100 m, 5 km (Mississippi)
Data: % sand, % coarse silt, % medium silt, % fine silt, % silt, clay-free or sand-free basis

13. Kesel *et al*. (1974:Fig. 3), Mississippi River, Louisiana
Catchment size: ?
Channel width: ca. 700-2000 m (?)
Floodplain width: ca. 0-17 km (? one side only)
Transect length: 10 km
Data: median diameter

Figure 4.94 (*following page*). Reduction in Grain Size With Increasing Distance From Stream Channel. Shown are three examples with transects of differing lengths, from differently-scaled streams. A, a nameless artificial channel in Wales (after Hughes and Lewin 1982:Fig. 3, C); B, American Creek, New South Wales, after Nanson and Young (1981:Fig. 5); C, River Swale, Site 13, England (after Walling, Owens, and Leeks 1997:Fig. 4, A). Note that the textural measure in "B" is simply the percentage of sand in the sample.

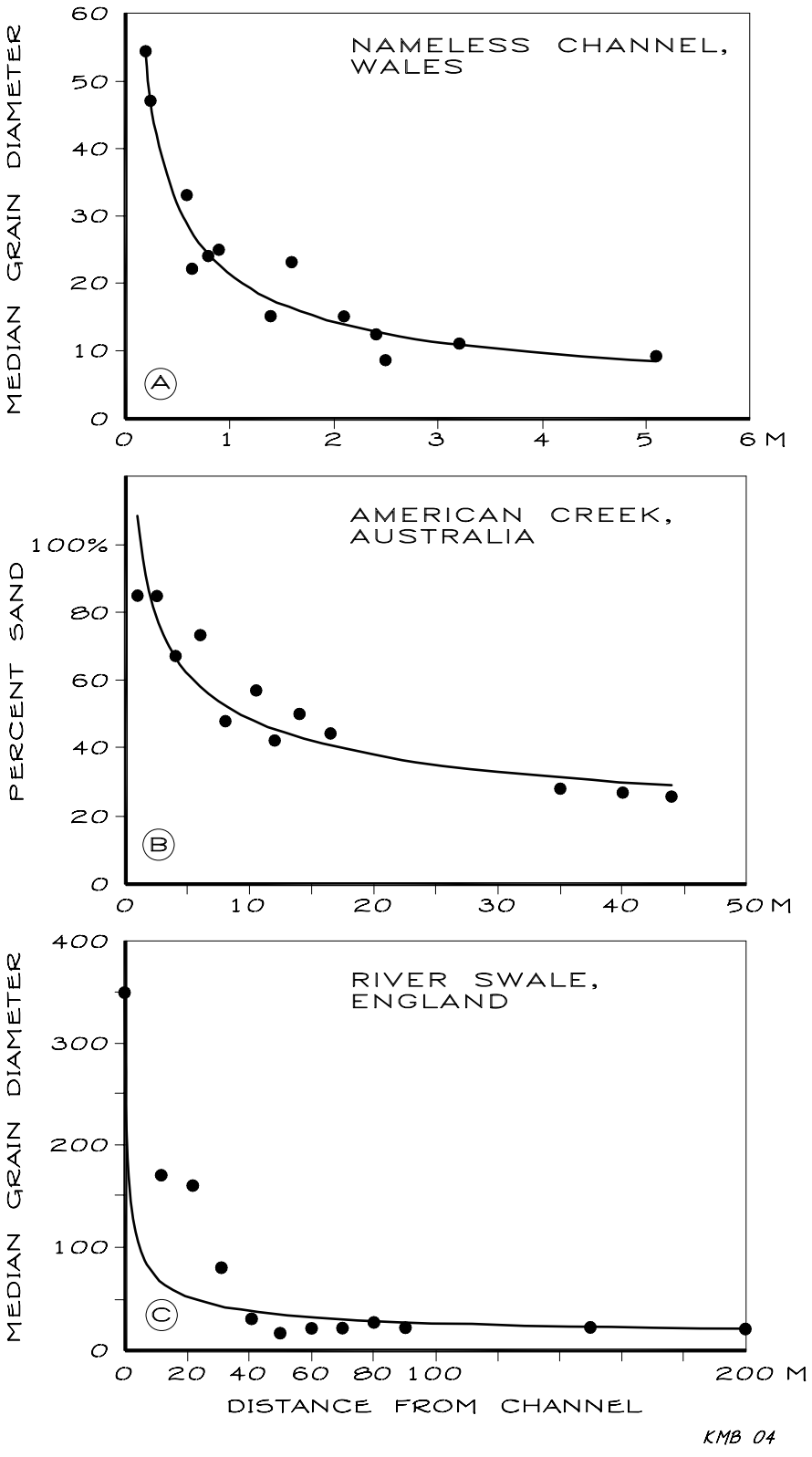
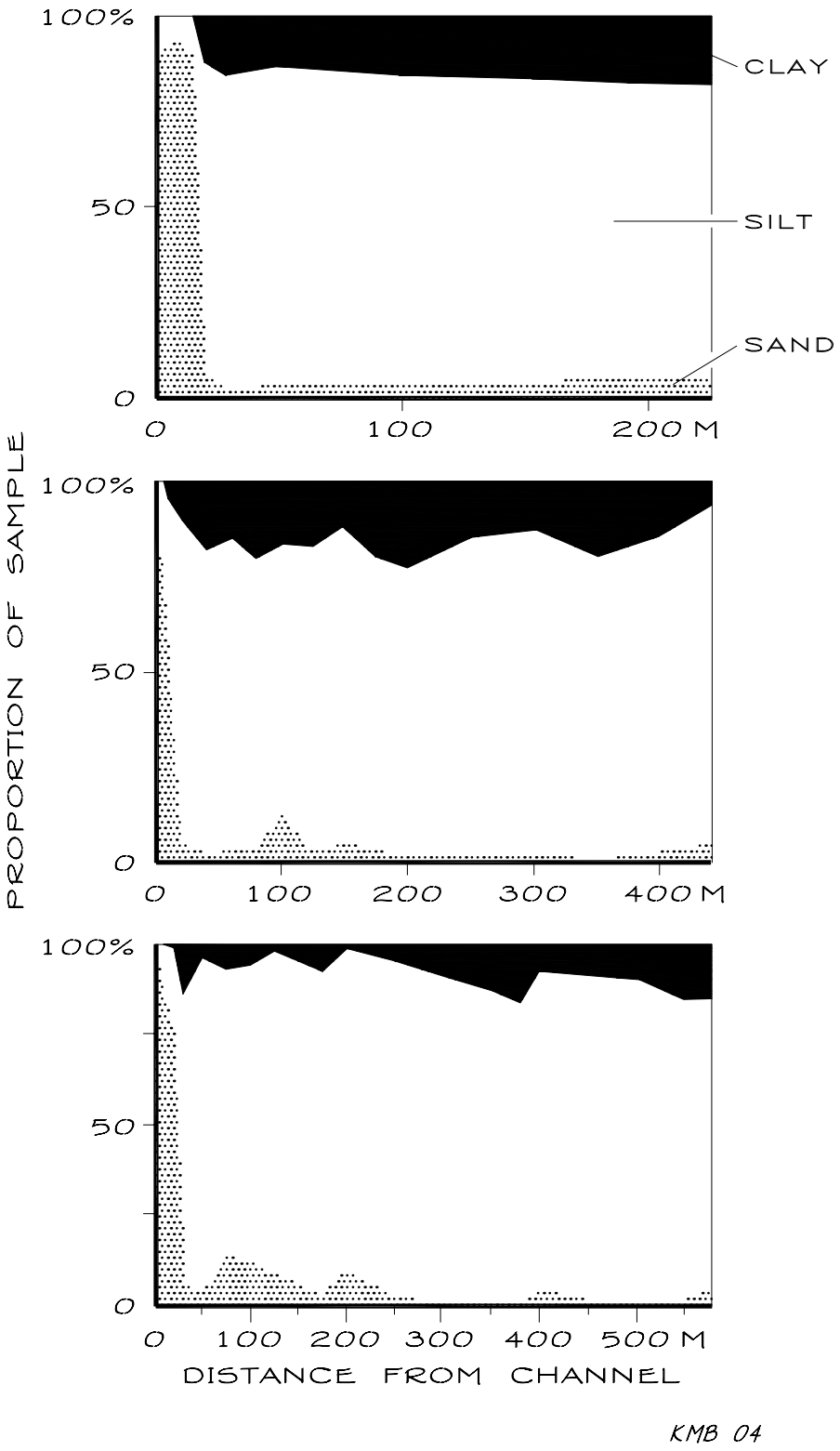

NAMELESS CHANNEL, WALES
MEDIAN GRAIN DIAMETER
60
50
40
30
20
10
0
0
1
2
3
4
5
6 M
A
AMERICAN CREEK, AUSTRALIA
PERCENT SAND
100%
80
60
40
20
0
0
10
20
30
40
50 M
B
RIVER SWALE, ENGLAND
MEDIAN GRAIN DIAMETER
400
300
200
100
0
0
20
40
60
80
100
200 M
DISTANCE FROM CHANNEL
C
KMB 04

Figure 4.95 (*following page*). Relative Proportions of Sediment Fractions With Increasing Distance From Stream Channel. Shown here are transects of different length from three sampling localities on the River Severn in Wales (after Marriott 1996:Fig. 3.5).Note the absence of clay from the levee facies in these silt-dominated floodplain deposits, and the scarcity of sand in the floodbasin facies. These are surface samples collected after a flood in 1990.


100%
50
0
CLAY
SILT
SAND
0
100
200 M
100%
50
0
0
100
200
300
400 M
PROPORTION OF SAMPLE
100%
50
0
0
100
200
300
400
500 M
DISTANCE FROM CHANNEL
KMB 04

This hypothesis is somewhat difficult to evaluate for the bench deposits. In the immediate vicinity of Berger Bluff, Coleto Creek appears fairly stable in position, with fairly low sinuosity and little evidence of lateral migration. It may well have had a more sinuous channel pattern when the bench sediments were accumulating, but the location of the channel is unknown. Because the northeast valley wall is gently sloping and mantled with Holocene sediments, the maximum valley width here is unknown. Maximum floodplain width is undoubtedly somewhere between 60 and 300 meters. It is unclear whether the Late Pleistocene floodplain was wide enough to allow the textural contrasts seen in the bench stratigraphy to develop by simple movement of the channel from one side of the valley to the other. The autocyclic hypothesis could have been tested by placing backhoe trenches at right angles to the creek axis, on the northeast side of the creek to look for buried paleochannels and evidence of stratigraphic continuity, but this was never done during any of the reservoir fieldwork. This is a good example of how lack of a holistic research design in cultural resource management studies can hamper later analysis. We can only conclude that hypothesis 4 (autocyclic bedding) is plausible but cannot be tested with the information at hand.

Hypothesis 5 (Allocyclic Bedding): This model proposes that submillennial climatic cycles and depositional processes are chiefly responsible for the textural contrasts in the bench deposits, all of which are overbank (floodbasin) deposits. Energy variations responsible for textural contrasts are extrinsic to the catchment and to the depositional system, and are ultimately provided by the climate system.

Sandy units accumulated in drier periods with more seasonal rainfall, when

1) upland ground cover throughout the catchment was sparser, rainfall infiltration rates were reduced, runoff and sediment production were enhanced,

2) discharge was flashier, higher peak energy was available to transport a coarser-grained sediment load, and

3) flood duration was shorter, providing less time for fine-grained suspended silts and clays to drop out of suspension (bedload-dominated stream, Fig. 1.41, *bottom*)

Muddy units accumulated in wetter periods with more even annual distribution of rainfall, when

1) upland ground cover was heavier, infiltration rates were maximized, runoff was slowed or minimized, and sediment production was reduced,

2) discharge was less flashy and more tempered, and unable to transport coarser-grained sediment, and

3) flood duration was prolonged, providing time for suspended load (especially fine-grained clays) to drop out of suspension (suspended load-dominated stream, Fig. 1.14, *top*).

This is essentially the explanation for sediment grading at Arenosa Shelter offered by Patton and Dibble (1982:116-117). Of the five hypotheses I have offered, this one is perhaps the most plausible because is consistent with the known (or estimated) stratigraphic and spatial constraints of the late Pleistocene/early Holocene Coleto Creek floodplain. The length of the proposed climatic cycles is unknown, but would probably amount to several centuries. As Table 1.1 shows, there are a number of different cycles ranging in length from 120 to 550 years identified in the GISP2 oxygen isotope data that might reasonably fit the known radiocarbon sequence from the bench deposits.

Of the four sediment humin samples submitted for radiocarbon assay, the two samples from sandy units have $\delta\ ^{13}C$ values that are slightly more negative (-21.0 ‰ and

–22.1 ‰) than the values from the muddy units (-18.3 ‰ and –19.0 ‰). These values are exactly intermediate between C3 and C4 plants, and represent about a 3 ‰ average contrast that could have possibly some climatic significance, although the small number of samples suggests caution in interpretation. The direction of the contrast is also opposite to expectations. If the sandy units represent more arid periods, greater proportions of C4 plants and *less negative* values (not more negative values, as determined) should be expected. The reason for this is unclear. It could have something to do with the greater propensity of the coarse-grained samples to admit contaminants through groundwater movement (?), or some other undiscovered cause. If, as the snail data seem to indicate, the floodplain was wooded, ^{13}C values closer to –25 ‰ might be expected.

Hypothesis 5 could also perhaps be tested by looking for systematic contrasts in biological remains from the sandy and muddy units. To some extent the distribution of the material limits our ability to do that. Animal bone is highly concentrated in one area of the site, and snail shell numbers diminish with depth, although diatoms are more abundant and evenly distributed. Subsequent chapters will examine this material, but meanwhile, to evaluate this hypothesis some further background is required, as follows.

Climate and Sedimentation Rates

The literature on the relationships between climate, erosion, vegetation cover, and sedimentation production and transport is extensive, but inconclusive and scattered among many different disciplines. In the United States, much of the empirical research has been done in the loessic region of the upper Mississippi River valley or in the semi-arid to arid Southwest, regions that differ climatically from the Berger Bluff catchment.

Soil scientists use a Revised Universal Soil Loss Equation that incorporates "cropping factors" and "conservation practice factors" that are not relevant to preagricultural situations. That are two aspects that need to be understood: 1) how climate change affects sediment yield in the catchment, and 2) how climate change affects sediment transport, deposition and grading – in other words, how might climate change affect grain size at the depositional site? Schumm (1977:25-30, 43-48) and Hooke (2000) provide useful comprehensive reviews. Some of the earliest research was by Langbein and Schumm (1958), who performed a synchronic review of sediment yields from 94 stations in the US. They found that sediment yields were minimal in arid areas, increased to a peak in areas with effective annual precipitation at about 12 inches (about 30 cm) and then declined with increasing precipitation (Langbein and Schumm 1958:Fig. 2, 3), because areas with higher annual rainfall had more extensive ground cover. The Berger Bluff catchment has about 2.7 times this much annual precipitation at present, and would have had equal or greater amounts in the Younger Dryas, with reduced evaporation rates due to somewhat cooler temperatures. The result would have been reduced sediment yield in wetter periods. Sediment yield declines very rapidly as ground cover increases (Fig. 4.96). A sediment yield curve constructed by Dendy and Bolton (1976) is similar, but peaks at about 50 cm (20 inches) annual precipitation (Hooke 2000:Fig. 2, A). Wilson compiled yet another curve, based on about 1500 drainage basins, that has two peaks at 76 cm and 177 cm of annual precipitation, with a minimum, with a minimum at about 100 cm (Wilson 1973:Fig. 1). Another data set compiled by Walling and Webb (1983:Fig. 4.5, also reproduced in Hooke 2000:Fig. 2, C) for 1246 stations is much noisier and almost trendless. A variety of studies from more restricted geographic areas, reviewed by Walling and Webb (1983:Fig. 4.7) suggest that sediment yield simply increases along with increasing mean annual precipitation despite any counterbalancing

effect of vegetation cover. All of these studies are, of course synchronic, and any attempts at predicting changes in sediment yield from changes in rainfall involve the substitution of space for time, possibly a questionable enterprise.

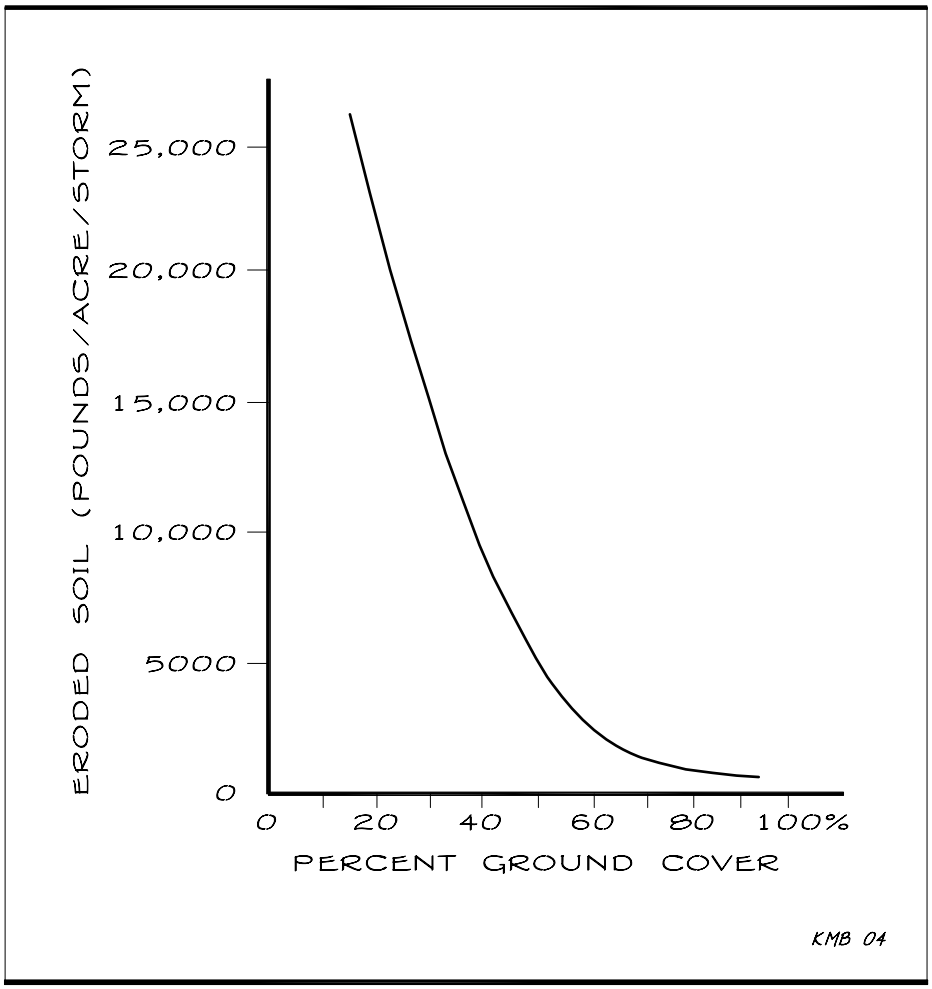


Figure 4.96. Sediment Yield and Ground Cover. After Schumm (1977:Fig. 2-3).

Mean annual atmospheric temperature is also relevant, because higher temperatures increase evaporation rates and therefore reduce the effectiveness of precipitation for creating ground cover. All other things being equal, rising atmospheric temperatures, such as those at the end of the Younger Dryas, should produce higher sediment yields (Fig. 4.97). Simultaneous rainfall reduction and increasing temperature should accelerate the effect. One modeling study done to anticipate global warming estimates that for each 1% change in precipitation, there is about a 2% change in runoff and a 1.7% change in erosion (Nearing, Pruski and O'Neal 2004).

Precipitation periodicity is probably more important than cumulative annual precipitation. Periods when rainfall events were highly clustered into a few intense storms (a more typically Holocene climatic pattern, Figs. 1.14, 1.15) would have been much more erosive than periods when precipitation was equably distributed throughout the year in smaller events (a Pleistocene pattern). This is substantiated by Wilson's study, which suggests that erosion rates are higher in areas with strongly seasonal climates (Wilson 1973:342). Periods with more intense rainfall events would have had reduced ground cover and higher runoff rates because of reduced infiltration time (Hooke 2000:1781).

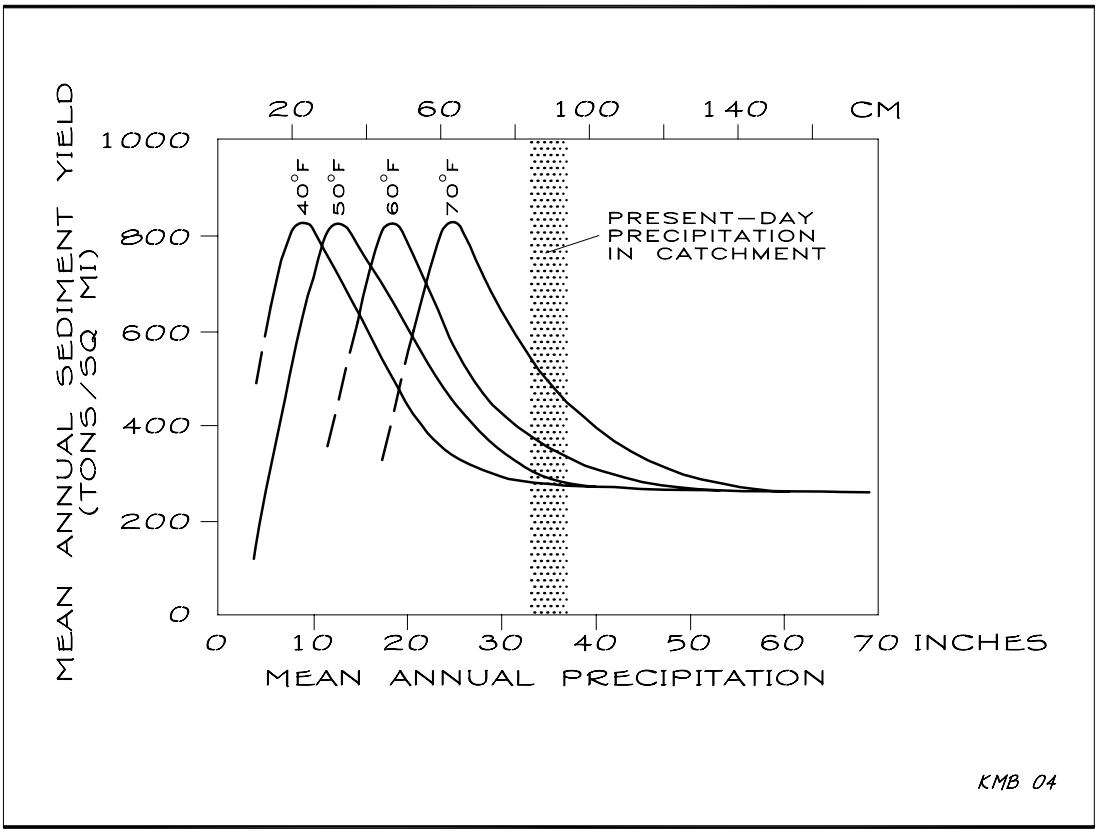


Figure 4.97. Effect of Temperature on Precipitation-Sediment Yield Relationship. Shaded band shows contemporary annual precipitation total for comparison (after Schumm 1977:Fig. 3-1). Higher temperatures encountered at the onset of the Holocene would produce higher sediment yields for a constant amount of precipitation.

A study of the Paria River basin in Utah and Arizona is particularly helpful because it is based on a restricted area with carefully documented discharge, suspended load, and aggradation records (Graf, Webb and Hereford 1991; Hereford 2002). The authors found that seasonal distribution of floods controls channel aggradation and degradation, and floodplain aggradation is a result of short-scale climate cycles:

> Flood-plain formation, therefore, began during a period of decreased frequency of tropical cyclones, and the greatest rate of aggradation occurred during the period of lowest frequency of tropical cyclones. Flood-plain aggradation appears to occur when floods are large enough to overtop existing deposits but are too small to significantly erode the deposits (Graf, Webb and Hereford 1991:1410).

It is also entirely possible that there may not be a linear relationship between precipitation and sediment yield (Tucker and Slingerland 1997). Schumm proposes a "complex response" of drainage systems:

> [Where] an event causing an erosional response within a drainage basin (tilting, changes of baselevel, climate and/or land use) creates a high sediment production, which in turn causes deposition and an increase of gradient. This, then is followed by incision of the alluvial deposits as the sediment load decreases. This sequence of events is the complex response…. (Schumm 1977:77).

Researchers who see a major role for allocyclic (climatic) control of sedimentation rates point to cases where depositional histories of various drainages are approximately in phase across large regions (for example, see Knox 1995 and especially Hereford 2002:Fig. 8). Researchers who do not see such a role point to cases where depositional histories of adjacent drainages are out of phase, and there are many examples of those, as well (Waters 1985).

Climate and Textural Changes

Sediment grain size is often used as a climate proxy in studies of cores extracted from marine (Poore and Wright 1999) and lacustrine environments. In continental lakes, cores are taken from depocenters (the "profundal zone") and pulses of coarser-grained sediment are usually taken to indicate wetter, colder or stormier periods when stronger stream discharge carried heavier particles into the center of the lake. This method has

been used both for open lakes (lakes with both inflow and outflow; Campbell 1998) and closed basins (Anderson 2001; Noren *et al*. 2002). Sediment pulses are taken to indicate higher stream discharge, but it is not always clear if higher discharge means prolonged wet periods, or simply more intense runoff events. Conceivably, a shift to a more seasonal, monsoonal rainfall pattern with infrequent severe storms could produce sediment pulses without any increase in annual precipitation – indeed, even in a climate with declining precipitation. However, in some cases the sediment pulses are also associated with reduction in salinity, based on proxy indicators such as ostracods or sediment chemistry. At Lake Estancia, the strongest sediment pulses are spaced about 200 to 400 years apart and tend to occur in clusters about 2000 years apart (Allen and Anderson 1993; Anderson 2001:77-78). Major pulses occurred at the end of dry periods, when renewed stream discharge flushed accumulated sediment into the lake.

The association of coarser-grained sediment pulses with wet periods in lacustrine settings is, to some extent, opposite to the relationship I have proposed in Hypothesis 5, but only because the lake studies have not distinguished between increases in annual precipitation and increases in precipitation seasonality. In fluvial floodbasin settings, I propose that finer-grained deposits will result from smaller magnitude, more frequent, longer duration floods (flat hydrograph, Fig. 1.14, *top*) and coarser-grained deposits will result from infrequent but large-magnitude, short-duration floods (peaked hydrograph, Fig. 1.14, *bottom*).

Except for the slackwater depositional system at Arenosa Shelter (Patton and Dibble 1982), examples of explicitly inferred allocyclic control on grain size in fluvial settings are difficult to find in the geologic literature, in part because so much research

emphasis has been placed on autocyclic mechanisms. Vittori and Ventura (1995) examined an extensive series of cores from the Po River valley in Italy, and reconstructed a chronology extending to 160,000 BP from an averaged core sequence 150 m deep. They attribute coarser-grained phases and higher sedimentation rates to glacial phases, and finer-grained, slower sedimentation rates to "temperate-wet" periods (Vittori and Ventura 1995:737-738). Large-scale studies like this in glacially influenced settings are not helpful for understanding floodplain deposition at Berger Bluff.

Aggradation and Incision

Much of the literature on Quaternary valley fills in the Southwest and Plains deals with alternating phases when sediment was first deposited, then either removed entirely by erosion (creating unconformities and missing sediment packages) or isolated as terraces left standing when streams incised below the former floodplain surface. And much of the literature deals with explaining this alternation between a two-state system consisting of aggradation and incision. At Berger Bluff, this is not particularly helpful because erosion has been a very minor part of the story. If there is any consensus about what type of climatic shift might cause streams to incise (disregarding other possibilities like tectonic uplift), it is probably that incision is mainly triggered by large floods (Hereford 20020 or up-basin sediment starvation. There is less consensus on whether large floods are more likely to occur in an arid phase or a wet phase. The view taken here is that extreme floods are more likely in arid phases (Patton and Dibble 1982; Leopold 1994:11; Molnar 2001; Hereford 2002), but incision was rarely the result in the Coleto Creek basin. Why should this be so?

It is helpful to contrast the history of Quaternary valley fills on the Edwards Plateau portrayed by Blum, Toomey and Valastro (1994) with that of the Berger Bluff catchment. They suggest that stripping of soil mantles from upland surface in the Late Holocene promoted rapid focusing of discharge into stream channels. Unlike the Edwards Plateau, however, the Berger Bluff catchment mostly consists of unconsolidated sandy sediments with very little exposed bedrock. Sediment production rates have presumably been consistently high throughout the Quaternary. Only two incisive episodes are documented in the stratigraphic section at Berger Bluff. The first is the incisive episode that immediately predates the accumulation of stratum 1. Other than this relationship, it is undated, but might correlate with the pre-Younger Dryas period of incision on the Edwards Plateau proposed by Blum, Toomey and Valastro (1994:15) at 14,000 to 11,000 RCYBP. A date somewhere near the onset of the Younger Dryas or somewhat before would be consistent with the known age of the bench deposits. The second is the equally problematical Late Holocene incision, whose date I have already discussed at some length earlier in this chapter.

The tentatively recognized *lower post-Beaumont terrace*, discussed much earlier in this chapter(Fig. 4.3, 4.4, Table 4.3), might indicate a mid-Holocene erosive event not represented at Berger Bluff, or it might simply represent localized lateral channel migration (six terrace remnants are identified in the area studied). At the Smith Creek Bridge site, which lies near Yorktown some 55 river kilometers upstream from Berger Bluff, about 1.8 m of Holocene sediments unconformably overlie Pleistocene sediments (Hudler, Prilliman and Gustavson 2002:27), suggesting that some sediment was likely removed here by erosion at some point during the first half of the Holocene. The dating of this erosive event is very uncertain, as there are no radiocarbon assays pertaining to

this part of the section and few time-diagnostic artifacts. A single Gower-like and a single Morhiss projectile point from the base of Unit II sediments (Hudler, Prilliman and Gustavson 2002:Table 11) provide conflicting estimates of the maximum age for Unit II (anywhere between 6950 and 3550 RCYBP). In any case, it is possible that there were Holocene erosive events in the Coleto Creek basin that simply are not represented at Berger Bluff.

Reconstructing Past Channel and Floodplain Configuration

The relationships between the variables of sediment load, discharge, channel sinuosity and width-depth ratio are well-established in fluvial geomorphology. The type of sediment load has a strong influence on channel cross-sectional shape (Shumm 1977:110-111). In general, streams carrying little bedload and those with fine-grained, cohesive banks are relatively narrow, deep, and sinuous (Leopold, Wolman and Miller 1964:202; Schumm 1977:117). Streams carrying coarse-grained bedloads, with sandy, noncohesive banks and streams with flashy discharge are shallow and wide, generally with low sinuosity – exactly like contemporary Coleto Creek before impoundment (see "The Contemporary Coleto Creek Fluvial System" in Chapter 1). Morton and McGowen (1980:39), describing lower Coleto Creek (near Highway 59), report a sinuosity of 1.37, a width/depth ratio of 16:1, and a gradient of about 38 cm/km. At Berger Bluff, the sinuosity is about 1.02 and gradient about 1.57 m/km (see "Channel Form and Bed Sediments" in Chapter 1). The width/depth ratio was about 120:1 if measured at the water surface during the period of fieldwork, but perhaps roughly 35:1 if measured at "bankfull" elevation. The creek bank is very poorly defined along much of the reach where the site is situated, so it is very difficult to specify a bankfull depth and width

accurately here, but the 76 foot contour interval on the URS/Forrest and Cotton topographic map can perhaps be taken as a rough marker.

Streams with noncohesive banks generally accommodate increased discharge rates by eroding the banks and widening, rather than bed scouring. The Cimarron River and Paria River examples already discussed provide good examples of this. Streams with cohesive banks accommodate increased discharge by experiencing overbank flooding. Schumm (1960) measured channel width, depth, bed grain size and channel grain size for 90 river cross sections in the Plains and computed the relationship (shown in Fig. 4.98) between the width/depth ratio and the weighted mean percentage of silt and clay. The weighted mean percentage of silt and clay (M) is computed as

$$M = \frac{Sc \times W + Sb \times 2D}{W+2D}$$

where Sc = percentage of bed silt and clay
Sb = percentage of bank silt and clay
D = channel depth
W = channel width
silt and clay = sediment finer than 0.074 mm

This weighting simply gives twice as much emphasis to the bank sediment as the bed sediment. Figure 4.98 clearly shows that the smaller the percentage of fines in the channel perimeter, the flatter the channel cross-sectional shape. Since neither W nor D are known for the Younger Dryas-aged creek channel at Berger Bluff, we cannot use this precise relationship to work backward from the known sediment texture to the channel shape. However, I have taken the data on bank texture from Schumm's (1960:Table 1) data and replotted it with arithmetic axes in Figure 4.99, fitting a logarithmic curve. Here the X axis is simply unweighted silt/clay percent in the channel bank. The r^2 value reduces to about 0.69 when this simplified version is used. We can take the

approximately equivalent textural data for the bench as a whole (63 % silt and clay for the entire bench), keeping in mind that Schumm defines "fines" as sediment below 0.074 mm and I define it as sediment below 0.0625 mm (Table 4.1). A very approximate width-depth ratio of about 30:1 can be read off on the Y axis of Figure 4.99, keeping in mind also that the bench textural data probably come from the floodbasin, not the channel bank.

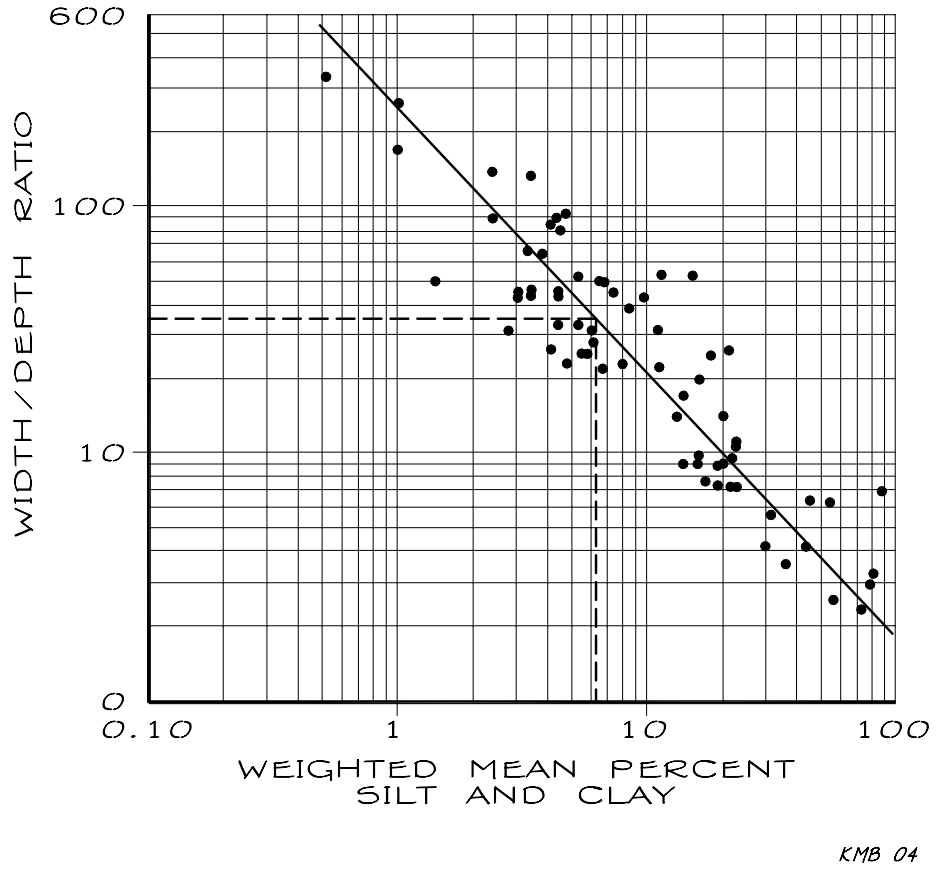


Figure 4.98. Effect of Silt and Clay on Width/Depth Ratio. This log-log graph shows the effect of weighted mean percent of silt and clay (M, see text) in the channel banks and bed on the width/depth ratio of the channel (after Schumm 1960:Fig. 8). The dashed line is the approximate width/depth ratio for pre-inundation Coleto Creek at Berger Bluff.

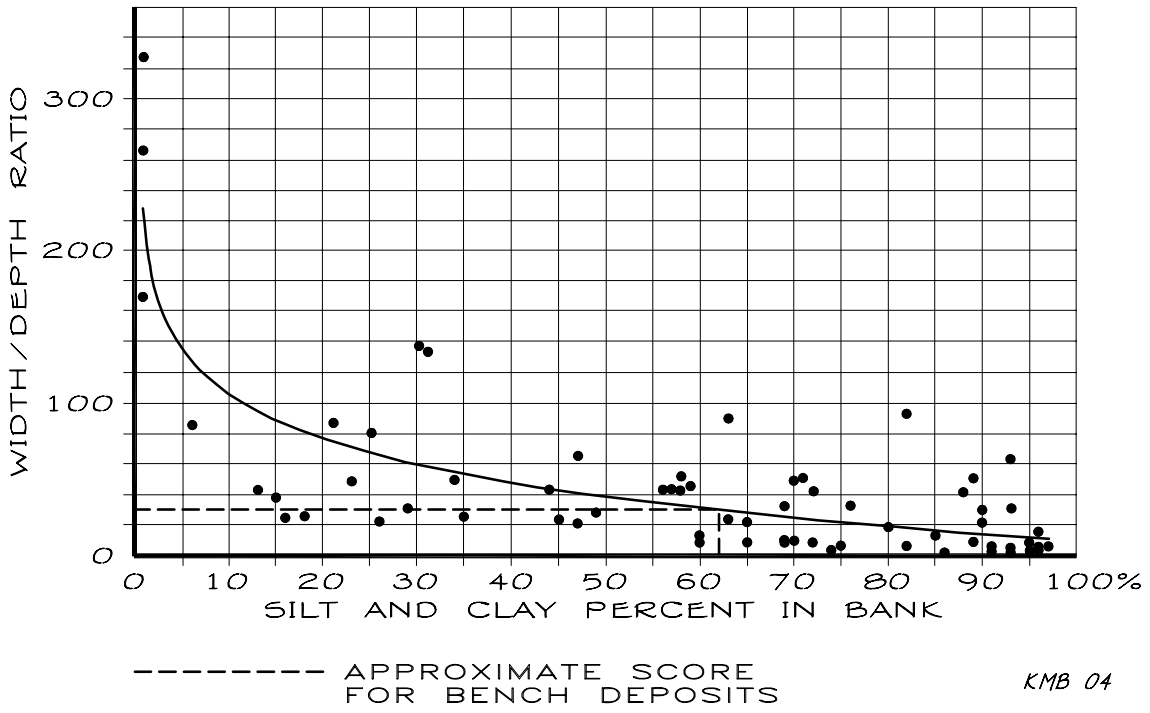


Figure 4.99. Effect of Silt and Clay in Bank on Width/Depth Ratio. This is a simplified version of most of the data shown in the previous figure. Here the axes are arithmetic and only the silt and clay percent in the bank is used. A log function is fitted to the first 69 cases in Schumm (1960:Table 1). The dashed line shows the relationship for the average silt and clay content (63%) of the bench sediments.

I suspect that this reconstructed 30:1 width/depth ratio is actually far too flat, given the evidence for very cohesive floodplain sediments, equable discharge, and relatively narrow floodplain width that would have characterized the Younger Dryas-aged valley. A steeply-banked channel with a width/depth ratio of anywhere from 3:1 to 10:1 would seem reasonable.

The floodplain itself would have been wider, flatter, and less drought-prone when the bench sediments were accumulating. Before reservoir inundation, the flood-prone zone was not morphologically well-defined. Coleto Creek is largely confined to its incised valley, but in severe floods can overtop the lowest terraces, as I have remarked in the section on the Preiss Ranch. In the Younger Dryas, the floodplain at Berger Bluff must have been wider and lower in order to accommodate the long-duration floods that left the substantial quantities of silt and clay at the bench. It must also have been rather flat, both because gradually settling sediments leave a flat surface, and because cohesive silty or clayey sediments would have resisted scouring (and drying, as well).

The Potential Role of Beaver in Coleto Creek Paleohydrology

Although giant beaver (*Castoroides ohioensis*, 60-100 kg body size) is known from a couple of localities in Texas, it is unlikely that it was present in the Coleto Creek drainage, especially in the time span under consideration. Furthermore, according to Kurtén and Anderson (1980:236), there is no evidence it built dams. However, modern beaver, *Castor canadensis* (18 kg body size, up to 27 kg), were likely present in the upper catchment throughout the Pleistocene and in at least the wetter parts of the Holocene, as the remains from the Smith Creek Bridge site suggest, even though no beaver remains have been found at Berger Bluff or any of the other nearby sites. Beavers prefer fast-growing riparian tree species such as willows (*Salix*) or cottonwood (*Populus*) for browse and will often clearcut floodplain stands of these trees. They extensively alter stream systems by dam-building, tunneling, and clearcutting (Naiman, Johnston and Kelley 1988). Dams may vary in height from as little as 20 cm to as much as three meters (Müller-Schwarze and Sun 2003:54).

Beavers are colonial rodents, and there are a few differences between Texas populations and their better-studied boreal counterparts. In Texas they live in cutbank burrows rather than in lodges (Schmidly 1994:377). In northern regions, beaver ponds may be frozen over and excluded from sedimentation for four to seven months of the year (Butler and Malanson 1995:260), but this is unlikely in south Texas, even in the Pleistocene.

Beaver ponds often occur in strings along a stream, creating a stepped-pool gradient. In Quebec, dam frequencies of 8.6 to 16 per kilometer have been documented (Naiman, Johnston and Kelley 1988:754; see also Gurnell 1998:Table 3). They tend to occur in headwaters, because floods may remove dams in lower reaches. Beaver dams potentially could have several different effects on stream hydrology, some of them perhaps mutually offsetting:

1) ponds intercept mineral and organic sediment loads, acting as settling pools and possibly causing sediment starvation in downstream reaches of streams, resulting in patchy distribution of grain sizes along the length of a stream (fine-grained sediment in ponds, coarse-grained in reaches between ponds or meadows; Gurnell 1998:181);

2) clearcutting around ponds removes riparian vegetation around ponds that otherwise might create turbulence and trigger sediment deposition (in other words, dams might *increase* sediment deposition in channel facies but *decrease* it in floodbasin facies);

3) dams even out flows in streams and flatten flood hydrographs, unless

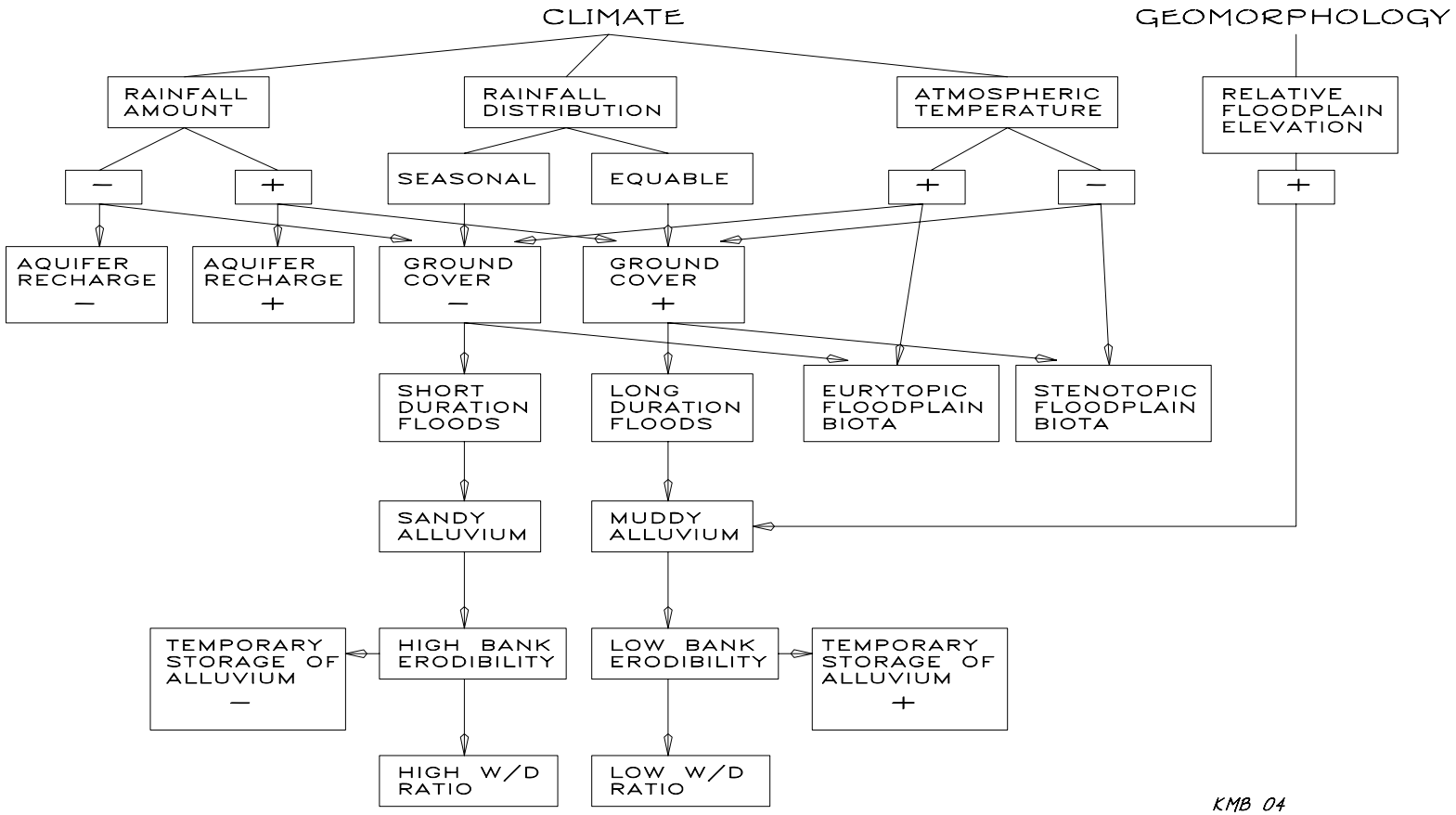
4) catastrophic failure of dams during flooding might cause extreme flood events and scouring downstream (cf. Schipke and Butler 1991; Gurnell 1998:182);

5) ponds create suitable habitat for amphibians, reptiles, and for freshwater mussels or other aquatic species that cannot tolerate turbulent flow (Müller-Schwarze and Sun 2003:128-129); they favor lotic over lentic taxa.

SUMMARY AND CONCLUSIONS FOR CHAPTER 4

The bench deposits at Berger Bluff represent Coleto Creek floodplain alluvium, fine-grained overbank deposits formed by vertical accretion near the south valley wall during part of the Younger Dryas, Preboreal, and part of the Boreal period. Along with a modern analog in the ravine, abundant phreatic carbonate suggests a spring or seep was nearby, although no physical evidence of an ancient spring was present in any parts of the site that were visible. Likewise, there is no direct evidence of the Pleistocene creek channel at the site – there are no major buried erosional contacts, point bar sands, or other lateral accretion deposits. Both the maximum depth and maximum age of stratum 1 are unknown. There is fairly conspicuous evidence of cyclic deposition during this early part of the Berger Bluff stratigraphic sequence, marked by alternating sandy and muddy layers of sediment. The reason for this cyclicity is uncertain. Submillennial climatic cycles (allocyclic variation) are perhaps the most likely cause, with the muddy units accumulating during wetter periods having more equable year-round distribution of rainfall, and sandy units accumulating during drier periods with more seasonally concentrated rainfall events (Fig. 4-100 presents a qualitative model for some of the major variables). Alternatively, it is also possible that cyclic variations in sediment texture are simply due to lateral shifting of the creek channel and its relative nearness to the bench area (autocyclic variation). Cyclic variation in grain size is superimposed upon a slight coarsening-upward trend that may represent climatic changes associated with regional warming at the end of the Pleistocene.

Figure 4.100 *(following page)*. A Stochastic Model for Cyclic Sedimentation. This flowchart represents what I think might be the relationships between major variables controlling cyclic sedimentation in the bench deposits. Not all of the potential variables are listed here; for example, stream gradient reacting to rising sea level, or possible beaver damming are not listed.


CLIMATE
GEOMORPHOLOGY
RAINFALL AMOUNT
RAINFALL DISTRIBUTION
ATMOSPHERIC TEMPERATURE
RELATIVE FLOODPLAIN ELEVATION
−
+
SEASONAL
EQUABLE
+
−
+
AQUIFER RECHARGE −
AQUIFER RECHARGE +
GROUND COVER −
GROUND COVER +
SHORT DURATION FLOODS
LONG DURATION FLOODS
EURYTOPIC FLOODPLAIN BIOTA
STENOTOPIC FLOODPLAIN BIOTA
SANDY ALLUVIUM
MUDDY ALLUVIUM
TEMPORARY STORAGE OF ALLUVIUM −
HIGH BANK ERODIBILITY
LOW BANK ERODIBILITY
TEMPORARY STORAGE OF ALLUVIUM +
HIGH W/D RATIO
LOW W/D RATIO
KMB 04

Present-day Coleto Creek is a bedload-dominated stream (Fig. 1.41, bottom), with large quantities of clean white sand in temporary storage as dunes and sandbars. From the Younger Dryas into the early Boreal period, the creek was a suspended load-dominated stream (Fig. 1.41, top). For the bench deposits as a whole, about 63% of the sediment consists of silt and clay. The presence of so much silt and clay in the bench deposits is a strong indicator that out-of-bank flooding was a fairly frequent occurrence, but floods were fairly prolonged and not erosive in nature. This amount of silt and clay also suggests the creek banks were fairly cohesive and the creek channel significantly narrower and deeper than at present. The fairly large *Amblema plicata* mussels found in the bench deposits are consistent with this interpretation. A high silt and clay content would also have made the floodplain deposits more resistant to seasonal drying, and the presence of rather abundant amphibians (salamanders, frogs, and toads) among the vertebrate remains suggests the floodplain was well-watered and vegetated, supporting a diverse and robust amphibian population. Many of the snails recovered from the bench deposits are characteristically associated with leaf litter, suggesting the floodplain was well wooded with a fairly continuous canopy of deciduous trees.

The source for the abundant phreatic carbonate and carbonate rhizoconcretions is believed to be the Evangeline Aquifer, and carbonate mobilized from the calcareous Miocene Goliad Formation bedrock near the site. The carbonate served to buffer the otherwise potentially acid floodplain quartz sands, resulting in good preservation of bone and diatoms, moderately good preservation of snail shell, and somewhat poor preservation of freshwater mussel shell. The carbonate also partially cemented the bench deposits, restricting erosion and bioturbation.

Together, the abundant phreatic carbonate and suspended-load sediments suggest the regional climate was significantly wetter, probably in large part because of reduced evaporation rates, and rainfall amounts were much less seasonal and more equably distributed during the year, resulting both in more consistent spring flow and less flashy stream discharge. Carbonate content is very high in stratum 1, possibly because it is capped by the fine-grained sediments in stratum 2A, but begins to decline in the upper part of stratum 1, reaching a minimum at the midpoint of stratum 2A. Above that, it fluctuates slightly before starting to increase again at the top of the section as stratum 3 appears. This might indicate spring discharge was highest early in the sequence, then declining but showing a slight resurgence late in the sequence.

Evidence from profiles, thin sections and ferromanganese concretions suggests that even though vertical accretion rates were probably rather slow, the floodplain sediments were sufficiently saturated during enough of the year to limit weathering and soil formation. Concretions, iron-manganese stains, structure (fissuring) and argillans suggest that the sediments experienced seasonal drying, mostly late in the stratigraphic sequence.

The top part of the bench deposits, representing the early Holocene, records several important events. Above stratum 2, phreatic carbonate is greatly reduced (although rhizoconcretions are apparently still abundant), suggesting that spring discharge was also greatly reduced. Above stratum 3, there is a major change in depositional style from *cyclic deposition* in strata 1-3 to *massive deposition* in strata 4 and 5. Pockets of gravel and coarse sand appear in stratum 2E and presumably at equivalent levels elsewhere in the bluff face. These are believed to represent coarse-grained bedload

material moved out of the channel and onto the floodplain surface by a major flood event, possibly one of the first hurricanes to enter south Texas from the Gulf as the Gulf waters warmed sufficiently to sustain hurricanes early in the Holocene. Alternatively, the flood event might have been triggered by the advent of one of the first Arctic cold fronts to enter Texas after retreat of the Laurentide ice sheet exposed the midcontinent to southward-penetrating Arctic airmasses early in the Holocene. Finally, clay (and perhaps silt) content is reduced as massive deposition of the somewhat coarser-grained stratum 4 begins.

These geomorphic events are clearly the result of regional warming and drying at the beginning of the Holocene. Reduction in spring discharge occurs first, suggesting a reaction by the Evangeline Aquifer to regional drying, followed by a series of related changes in stream behavior that represent concentration of rainfall into seasonal peaks (much like today's rainfall pattern, Figs. 1.14, 1.15) and at least one major flood triggered either by a hurricane, an Arctic cold front, or possibly even jetstream-directed weather associated with an early El Niño event (there are several kinds of these characteristically Holocene weather events that could produce a major flood).

None of these events can be precisely dated. The highest (both stratigraphically and in elevation) radiocarbon assay available is AA2831, 9880±90 RCYBP, collected at 92.75 m in stratum 2D. All of these events occur somewhat above that level, and hence later by an unknown amount of time. Reduction in phreatic carbonate occurs an unknown number of centimeters above AA 2831. The top of stratum 3 occurs almost 80 cm above AA 2831. The base of stratum 2E, the coarse-grained flood event, rests at about 93.18 m, or 43 cm higher in absolute elevation than AA 2831. The best estimate for the timing of

these environmental changes would be some time early in the Boreal period, or well into the early Holocene.

As we have seen in Chapter 2, the major climatic transition in the Greenland summit ice cores occurs at about 10,091 RCYBP, or about two radiocarbon centuries before AA2831. Why are these significant environmental changes in the Coleto Creek basin lagged well after the abrupt end of the Younger Dryas in the ice cores? I suspect a major part of the reason is the series of delayed glacial meltwater flooding events (MWF5A through MWF5G) identified by Aharon (2003), extending from 9970 to 8900 RCYBP that affected the Gulf at the same time as the events I have identified above. These meltwater pulses (see Chapter 2) were probably still entering the Gulf at the same time that stratum 3 was accumulating, and it was only after their effect was dissipated that major hydrological changes began to take effect in the Berger Bluff catchment. The meltwater pulses probably played a major role in delaying and buffering the response of the circum-Gulf environment to the onset of the Holocene.

The bench deposits are coeval in part with Unit I as defined by Waters and Nordt (1995:Fig. 4) in the Brazos River drainage, Georgetown Alluvium as defined by Nordt (2004) for Cowhouse Creek at Fort Hood, Columbus Bend Allomember 1 as defined by Blum and Valastro (1994:Fig. 9) in the lower Colorado River drainage, the Q2 terrace on the Sabinal River as defined by Mear (1995:Table 3), the lower part of the Applewhite Terrace on the Medina River (Thoms 1992:Fig. 3), and the Post-Deweyville Unit 1 on the lower Nueces River as defined by Durbin (1999:119-126), but the upper and lower age limits on these units as defined show wide discrepancies. Likewise, some of these units are terminated by alvulsion or erosion and floodplain abandonment and some are capped

by paleosols, while at Berger Bluff the record is one of continuous deposition overprinted by major changes in depositional style.

Although the Late Pleistocene/Early Holocene depositional histories of these different drainages show some general similarities, when examined in detail they are clearly out of phase. This is not surprising, given that the basins vary widely in size and are placed in contrasting climatic regions. Both the Brazos and Colorado drainages, for example, originate in New Mexico in a vastly different climatic regime. Large streams like these pass through so many different climatic and geologic zones that their depositional histories are a compound of many different factors. Smaller basins like the Berger Bluff catchment are likely to be much more responsive to local or regional environmental changes. Lee Nordt (2004:299) reaches the same conclusion when comparing Cowhouse Creek with the much larger Brazos River basin.

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MAPS

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Chapter 5: Radiocarbon Assays

INTRODUCTION AND HISTORY OF ANALYSIS

There are 11 radiocarbon assays from the bench deposits (Table 5.1), but none of the testing or mitigation projects in other areas of the site have produced any assays. Seven of the assays are for wood charcoal, and the other four are for the humin fraction of sediment samples. Samples for radiocarbon analysis were submitted over a period of several years, and four different radiocarbon labs are involved. Detailed data on each sample are provided later in this chapter. Only one of the charcoal samples was large enough for species identification.

In nearly every archeological project that produces radiocarbon results, there are more samples available than can be analyzed, and some sort of selection process (rarely discussed in the report) structures the final outcome. In the case of Berger Bluff, the first samples analyzed were submitted before commercial atomic mass spectroscopy (AMS) analysis became available, and this has had consequences for the dating program. Some samples that could more profitably have been analyzed by AMS were expended then. There remain in the collections, from various proveniences, a number of small bits of wood charcoal that have not been submitted for analysis.

Table 5.1. Uncalibrated Radiocarbon Assays from the Bench Deposits.

Fld no.	Lab sample number	Radiocarbon yr BP	Material assayed	Type	Unit coordinates	Elevation (m)	Strat
17	AA 2831	9880±90	charcoal	AMS	N109 E96	92.75	$2D_2$
30	GX-17034-II	9855±310	humin		N111 E101	92.70-92.65	2C
22	BETA 73471	10,280±110	charcoal	AMS	N113 E98	92.55	2C/2B
33	GX-18867-AMS	8926±90	humin	AMS	N111 E101	92.40-92.35	2B
1	Tx 3569	11,550±800	charcoal	LS	Unit 2	92.38	2B
5	AA 2830	8460±70	charcoal	AMS	N110 E102	92.21-92.20	2A[1]
10,	Tx 4095	7770±810	charcoal	LS	N112 E99	92.16	2A[2]
23,	—	—	—	—	N113 E98	92.15-92.10	2A[2]
24	—	—	—	—	cutbank	not recorded	2A[2]
25	AA 2832	10,070±80	charcoal	AMS	N111 E101	92.14-92.11	2A[3]
31	GX-17035-II	11,305±330	humin		N111 E101	92.15-92.10	2A
9	BETA 16979	10,190±160	charcoal	AMS	N111 E101	92.07	2A[4]
32	GX-18866-AMS	8114±93	humin	AMS	N111 E101	91.95-91.90	1

NOTES

AA, BETA, and Tx samples are wood charcoal, most of it plotted in place. AMS samples are ^{13}C corrected for fractionation; for charcoal, a value of -25‰ is assumed; for humin, the value was measured and is shown in Table 5.3. Tx dates are not ^{13}C corrected. GX samples are on humin fraction of bulk sediment samples; humic acid extraction was also done on two of these samples but no significant amount of humic acid was present. The combined sample (field numbers 10+23+24) assayed as Tx 4095 is rejected (see text). Method: AMS = accelerator mass spectroscopy; LS = liquid scintillation counting

[1] from upper contact of stratum 2A

[2] three subsamples combined, all from surface on which mussel shells rest

[3] from mid-stratum 2A, near poorly defined mid-stratum contact

[4] from lower third of stratum 2A

The first sample submitted was Tx 3569, wood charcoal collected from Feature 5, the hearth exposed in the cutbank. Sonny Timme and I collected this sample on June 26, 1979, while work was in progress in the blufftop excavation block. The sample consisted of various small bits of wood charcoal scattered across the surface of the hearth which, when first exposed, was obviously well-baked and fire-reddened. This sample was submitted by David Brown to the University of Texas Radiocarbon Lab and assayed by conventional liquid scintillation beta-counting. The sample was small, and despite counting for three days produced a ±800-year standard error. Had this sample been analyzed by AMS methods, the standard error could have probably been reduced by a factor of ten. The chief purpose for submitting the sample was simply to get some idea of the age of the hearth and verify that it was not recent. Despite the fact that the edge of the hearth was exposed in the cutbank, it produced what I consider to be a valid age estimate, although one with an unfortunately large standard error.

All subsequent samples came from the mitigation project (various dates, November 7, 1979-April 18, 1980) in the bench deposits. The next sample submitted was Tx 4095, a composite sample consisting of wood charcoal from two excavation units and one location in the cutbank. The purpose of this sample was to get some kind of age estimate for the mussel shell-bearing surface visible in the cutbank and in many of the excavation units. This surface appeared to be a widespread “marker horizon” that might be recognizable over much of the site, although it is not clearly marked by anything except scattered mussel shell, and I hoped to obtain a good age estimate that would apply across the entire bench area. Combining samples from different proveniences was plainly very undesirable, but all of the samples were clearly associated with the mussel shell surface, and without AMS methods yet available, there was no way to obtain a second

assay anywhere in the deposits short of combining samples. The sample was analyzed (it too had to undergo extended counting) and produced a date that is clearly far too recent, with an even larger standard error. The culprit may be the cutbank subsample. In analyzing organic fractions from buried soils at Lubbock Lake, Haas, Holliday and Stuckenrath (1986:481) discovered that samples from the walls of excavations that had been left standing open for several years produced assays that were younger than those from freshly scraped walls. The cutbank at Berger Bluff was damp from capillary wetting by the creek; mold growth might have been a source of contamination in the cutbank sample of wood charcoal.

Two additional samples (AA 2832, wood charcoal, and GX-17035-II, sediment) were submitted much later in a further effort to produce an age estimate for the shell-bearing surface, and these gave much better results.

After the two samples analyzed by conventional beta-counting at the University of Texas, five more charcoal samples were analyzed by AMS methods (three at the University of Arizona accelerator facility, two at Beta Analytic using an accelerator facility in Zurich, Switzerland). These all yielded very plausible dates, but there were a good many inversions when the uncalibrated midpoints were listed stratigraphically. Although, as discussed in Chapter 4, bioturbation is believed to be rather minimal because of phreatic carbonate cementation, the possibility remains that some of the date inversions could be the result of small-scale bioturbation. With the possible exception of AA 2831, none of these samples are associated with a feature. Instead, they are well-provenienced but isolated bits of wood charcoal found *in situ.*

Pretreatment procedure for wood charcoal performed by Beta Analytic consists of mechanical cleaning, crushing, washing in deionized water, further rootlet removal, an HCl acid wash, an NaOH alkali wash, and a final acid wash (letter from Darden Hood, July 18, 1994). No information on pretreatment was provided by the University of Texas or the University of Arizona facilities, but the protocol used by the University of Texas lab for charcoal as of 1997 is summarized from the lab's web site as follows:

> Sample is washed with hot water in a USGS sieve to remove sediment, crushed, boiled for 10-60 minutes in 2% HCl to remove carbonates. Sample is left to cool and digest in the acid bath overnight, then washed repeatedly with distilled water until pH is 5.5. Sample is then boiled in 2% NaOH to remove humic acids, left overnight, then washed repeatedly with distilled water until the pH is 5.5. Because NaOH tends to absorb modern CO_2 during removal of humic acids, the sample is again immersed in cold 2% HCl and washed repeatedly with distilled water, then dried overnight at 100° C and given a final visual inspection for contaminants.

On the premise that bulk sediment samples were much less likely to be affected by bioturbation than small bits of wood charcoal, I decided to experiment with assays on bulk sediment samples extracted from the archived matrix sample column collected from unit N11 E101. Four bulk sediment samples were submitted to Geochron Laboratories in 1991 and 1994.

ASSAYING SEDIMENT AND SOIL SAMPLES

Although both buried sediments and buried soils can contain enough organic carbon for radiocarbon assay, the carbon source differs. Abbott (1996:153-158) provides a good review of the topic, and Matthews (1985) provides a good review of soil dating.

Soils form on stable or slowly aggrading surfaces, where autochthonous organic matter is added to the surface by annual or perennial plants, then is translocated downward by bioturbation, accretion of the surface, or both. Because of continual addition of new organic matter at the surface, the upper part of the soil contains carbon with greater radiocarbon activity than that in the lower part of the soil. Radiocarbon assays on soils yield a date (*mean residence time*) that is an average for the different generations of carbon present. In cases where part of a soil has been sealed, for example in sites covered by burial mounds of known age, the sealed part yields older radiocarbon assays than the uncovered part (Alexandrovskiy and Chicagova 1998). The rate of carbon cycling is also proportional to temperature.

Sediments contain mostly allochthonous organic carbon that arrives in three forms: 1) Relatively undegraded, floating litter, organic debris, or driftwood. This matter either floats or is transported high in the water column and can be deposited as a thin organic drape after flooding or as more patchy, localized debris deposits. It represents recent organic matter that is roughly the same age as the depositional event. 2) Degraded or partially degraded organic matter, either waterlogged wood or organic debris, dissolved organic carbon (DOC) in stream water, or degraded, particulate humic substances. It is transported lower in the water column and may be deposited in the form of patchy debris jams or evenly dispersed in flood sediment packages, and is likely to be variably aged, but older than the flood event. As an example, Rice and MacCarthy (1989:45) sampled bed sediment from a creek in Colorado and found the sediment contained 7% organic carbon on a dry weight basis. Humin represented 58.4% and humic acid 35.9% of total organic carbon. 3) Finely particulate, degraded humic compounds adhering to clay particles, transported throughout the water column but deposited only

when conditions are right for precipitation of clays. Minor amounts of autochthonous organic carbon can also accumulate on floodplain surfaces from *in situ* vegetation growth (in which case the sediment might be considered an *entisol* or *fluvent* by soil scientists).

Floodplain vegetation patches and topographic lows, such as oxbows and scour pools are facies that typically accumulate large amounts of organic matter. Since accumulation is essentially a discontinuous process, the concept of mean residence time does not apply. In general, most buried floodplain sediments probably contain less organic carbon than buried soils (cf. Haas, Holliday and Stuckenrath 1986:479), but the potential for patchy concentrations of carbon is always present. In some cases, a significant amount of authochthonous carbon may be present. At the Wilson-Leonard site, Stafford (1998:1053-1054) argues the organic carbon in Unit I cienega muds is derived mostly from aquatic plants growing in or on the mud.

For sediments, a principal source of error is the possibility that substantial quantities of fossil carbon may be exposed by erosion upbasin and redeposited at the site of interest (Fowler, Gillespie and Hedges 1986:442). Fossil carbon could include older charcoal or other relatively inert humic substances exhumed from fossil soils. According to Abbott,

> The major assumption that must be made in dating sediments is that the organic material is penecontemporaneous and can provide a good estimate of the sediment age… if the organics have previously been in storage elsewhere (e.g., accumulating for thousands of years as an upland soil that is then converted to an organic sediment by erosion) then the estimate provided can be significantly older than the age of deposition (Abbott 1996:155).

In the case of Berger Bluff, an additional possible source of error is fossil carbon in the form of phreatic carbonate and radiocarbon derived from groundwater. The carbonate is redeposited from the Miocene-aged Goliad Formation bedrock and should show no radiocarbon activity. Carbonate should be removed by sample pretreatment, but some of the carbonate cement is very resistant to acid digestion. Groundwater in other southern Plains aquifers typically shows radiocarbon activity with time lags of several centuries to millennia. If the sediment contains significant amounts of autochthonous organic matter that has grown on-site and has incorporated dead carbon, there can also be a "reservoir" or "hard-water" effect that will not be removed in sample pretreatment (Fowler, Gillespie and Hedges 1986:446-447; Stafford 1998:1052). Because only one of the humin samples (GX-17035-II) seems somewhat anomalously old, neither fossil carbon nor reservoir effects appear to be the major source of error in the sediment dates.

Regardless of whether soils or sediments are sampled, organic matter is usually treated as three separate fractions. These are complex compounds that are defined not by their composition, but by the lab methods used to extract them. These are:

Fulvic acid (soluble in alkali, soluble in acid)
Humic acid (soluble in alkali, insoluble in acid)
Humin (insoluble in alkali, insoluble in acid)

From top to bottom, these three fractions generally have progressively greater molecular weight, carbon content, and resemblance to lignin (Swift 1985:Fig. 1), and in some cases, progressively older radiocarbon ages. However, there is little consistency in the relative ages of these three fractions (Martin and Johnson 1995:233; Shore, Bartley and Harkness 1995). In some cases, fulvic acid is youngest and humic acid is oldest

(Campbell 1967:Table 1). In some cases, the humin fraction is older than the humic acid fraction (Walker *et al*. 2001) and in others, the humic acid fraction is often older than the humin fraction (four out of five cases in Haas, Holliday and Stuckenrath 1986:Table 3). At the Wilson-Leonard site, the humic acid fraction was consistently older than either the humin fraction or bulk decalicified sediment (Stafford 1998:Fig. 25-7). In the study by Walker and others, fossil pond sediments were assayed and in 15 out of 17 cases, the humin fraction was older than the humic acid fraction (by an average of about 440 radiocarbon years; Walker *et al.* 2001:Table 1).

There are relatively few studies that compare bulk or fractionated sediment or soil organic matter to charcoal from the same soil horizon or layer. When five paired charcoal-humate assays from Late Holocene contexts at Fort Hood were run, the "bulk humate" samples consistently dated 401-1317 radiocarbon years older, and the MRT for the humate samples appeared to increase with depth (Quigg and Ellis 1994:Table 8.20). A study from Brazil found that humin assays were roughly equivalent to charcoal in six cases, younger in nine cases, and older in two cases (Pessenda, Gouveia and Aravena 2001:Table 3).

SEDIMENT ASSAYS FROM THE BENCH DEPOSITS

In the case of Berger Bluff, analysis of both the humic acid and humin fractions was requested for the first two sediment samples (GX-17034 and GX-17035) submitted to Geochron Laboratories in 1991, but in both cases, insignificant amounts of humic acids were extracted and no assays were possible for the humic acid fraction. Likewise, for the two samples submitted in 1994 and analyzed by AMS (GX-18866-AMS and GX-18867-AMS), only the humin fraction was analyzed. The unanalyzed humic acid

fractions were given the lab code suffix I and the humin fractions were given the suffix II.

Laboratory procedure is as follows:

> The sample was disaggregated, dispersed in deionized water, then whatever remained in suspension after "a few seconds" (telephone conversation with Hal Krueger, July 22, 1994) was drawn off and treated with HCl until all carbonates were removed. Clays and organic matter were separated from any sand and silt, and washed free of excess acid. The sample was then digested in warm dilute NaOH to dissolve humic acids. The supernatant solution was recovered and acidified to precipitate humic acids for analysis. The material remaining after humic acid extraction was washed free of NaOH, acidified, filtered, and dried. The residual material was roasted in oxygen to combust any humins or other resistant organic matter, and the carbon dioxide was recovered for analysis.

The sediment fraction analyzed, then, is a combination of silt and clay (<50 microns, according to Krueger). This procedure has worked well for samples with as little as 0.01% carbon. The pretreatment does not use nitric acid. The NaOH wash is substantial and normally more than adequate to remove humic acids; it does not get exhausted and leave any humic acid residue (telephone conversation with Hal Krueger, July 22, 1994).

Most of the organic carbon in the humin samples from the bench is probably associated with the clay fraction, as organic carbon content is often positively correlated with clay content (Quiroga, Buschiazzo and Peinemann 1996; Amelung *et al*. 1998).

> It is already well-known that there is a particle size fractionation effect in soils, and I would presume it fairly safe to assume that the same is true for sediments. There are several references which back this up. The theory is that the fine fractions (especially clays) hold interlayer clay-organic complexes, which are presumed to have been present more or less since the time of soil formation/original pedogenesis (i.e., the first humus formation). These compounds (largely thought to be aliphatic in nature) are extremely stable and

recalcitrant, and once bound, are thought to be virtually inert to biological alteration (Pete Falloon, personal communication 1997, Institute of Arable Crops Research-Rothamsted, Hertfordshire, England).

Table 5.2 shows some data for a modern soil in Saskatchewan assayed by Anderson and Paul (1984). The humic acids were extracted by an alkali-pyrophosphate process that differs from the standard radiocarbon lab procedure. Humic acid A is the alkaline pyrophosphate extract, and Humic acid B is the "humus=clay" extract. Table 5.2 shows that the radiocarbon age is proportional both to the organic carbon content and (with the exception of the fine clay fraction) to the fineness of the sediment grade. The coarse clay fraction has the oldest radiocarbon age. The authors offer no explanation for why the fine clay grade is different, but note that electron microscopy shows the organic matter in the coarse clay fraction includes many humified microbial cell walls.

Table 5.2. Grain-Size and Radiocarbon Data from the Melfort Soil, Saskatchewan.

Fraction	Proportion of organic carbon	Radiocarbon age, RCYBP
Chemical fractionation		
Humic acid A	0.32	1425 ± 95
Humic acid B	0.21	705 ± 70
Fulvic acid	0.09	1140 ± 55
Size fractionation		
Sand (not analyzed)	no data	no data
Coarse silt (50-5 μm)	0.25	800 ± 50
Fine silt (5-2 μm)	0.29	965 ± 45
Coarse clay (2-0.2 μm)	0.31	1255 ± 60
Fine clay <0.2 μm)	0.08	170 ± 50

Source: Anderson and Paul (1984:Table 3), data from Canada Dept. of Agriculture Research Station, Melfort, Saskatchewan.

Scharpenseel and Becker-Heidmann (1992:545 and Fig. 2) also find that zones with the highest clay content also produce the oldest radiocarbon ages and conclude that "clay organic complexes, once formed, do not easily exchange the organic component with infiltrated younger humus components." It seems likely that most of the organic carbon in the bench samples was adsorbed to the edges of clay particles (Birkeland 1984; Varadachari, Mondal and Ghosh 1995). Table 5.3 shows properties of the four humin samples and suggests that the relationship proposed by Scharpenseel and Becker-Heidmann seems to apply fairly well. The oldest assay (GX-17035) comes from the most clay-rich sample, the next oldest (GX-17034) from the second most clay-rich sample, and the sample that probably has the least clay (GX-18866) has the youngest date, one that appears far too recent for its stratigraphic position. Note that there are no grain-size data from N111 E101, but clay content can be estimated from visual inspection of profiles and from the magnetic susceptibility data. I suspect that the humin age is at least partly controlled by the grain size of the sample. GX-17034 shows very good agreement with a stratigraphically comparable charcoal sample (AA2831). GX-17035 is somewhat older than expected, and the remaining two assays are younger than expected, especially GX-18866, which is clearly far too recent.

Table 5.3. Radiocarbon Assays on Sediment Humin From the Bench Deposits.

Lab sample number	Uncalibrated date RCYBP	$\delta\ ^{13}C$ value	Stratum	Type of deposit	Lo-freq chi value
GX-17034-II	9855 ± 310	-19.0 ‰	2C	muddy	5.683217
GX-18867-AMS	8926 ± 90	-22.1 ‰	2B	sandy	5.762890
GX-17035-II	11,305 ± 330	-18.3 ‰	2A	muddy	7.182827
GX-18866-AMS	8114 ± 93	-21.0 ‰	1	sandy	5.214948

DOCUMENTATION FOR INDIVIDUAL ASSAYS

The assays below are ordered by absolute elevation, from highest to lowest. Most of the same information is presented in tabular form in Table 5.1. Note that all labs use the Libby halflife, by international convention, but Beta Analytic and the University of Texas Radiocarbon Lab interpret that as 5568 years, while Geochron interprets it as 5570 years. Calibrated dates are based on CALIB 4.4 (Stuiver and Reimer 1993), using the INTCAL98 terrestrial database (Stuiver *et al*. 1998).

AA 2831 (Fig. 5.1)

Uncalibrated age: 9880 ± 90 RCYBP

Calibrated age at 1 sigma:

cal BP age ranges	Area under probability distribution
11,177-11,342	0.829
11,390-11,404	0.045
11,509-11,547	0.126

Field sample number: 17

Lab: University of Arizona

Material assayed: *Juniperus* sp. wood charcoal

Counting method: AMS

Stratum: $2D_2$

Provenience: N109.08 E96.70 (92.75 m)

When analyzed: 1988

Remarks: This charcoal was found adhering to the underside of a large rock that was part of a scatter of rock and freshwater mussel valves in the upper levels of unit N109 E96 (Fig. 4.52). A composite drawing compiled from four different level plans can be seen in Fig. 4.50 (top). This debris scatter is clearly cultural in origin, and the sample is clearly in

place, not displaced by bioturbation. The debris scatter may be associated with a small rock cluster (see Fig. 3.1 for location) discovered in the corner of the area where overburden was removed from the toeslope. Bone, snail shell, mussel shell fragments, discolored sandstone fragments, hackberry seed fragments, and a chert flake fragment were recovered from the two 5 cm excavation levels immediately above and below 92.75 m. In the Coleto Creek basin, the most likely species of juniper is probably eastern red cedar, *Juniperus viginiana* (Espey, Huston & Associates 1976:Table 2-18), occurring most often in upland settings, often as an invader species in disturbed habitats. It is perhaps not common in riparian settings except in headwater reaches of streams. Another possibility might be southern red cedar, *Juniperus silicicola*, more likely to be found in riparian settings but not currently reported from the area. Date shows excellent agreement with GX-17034-II. A $\delta\,^{13}C$ value of –25 ‰ is assumed, not measured.

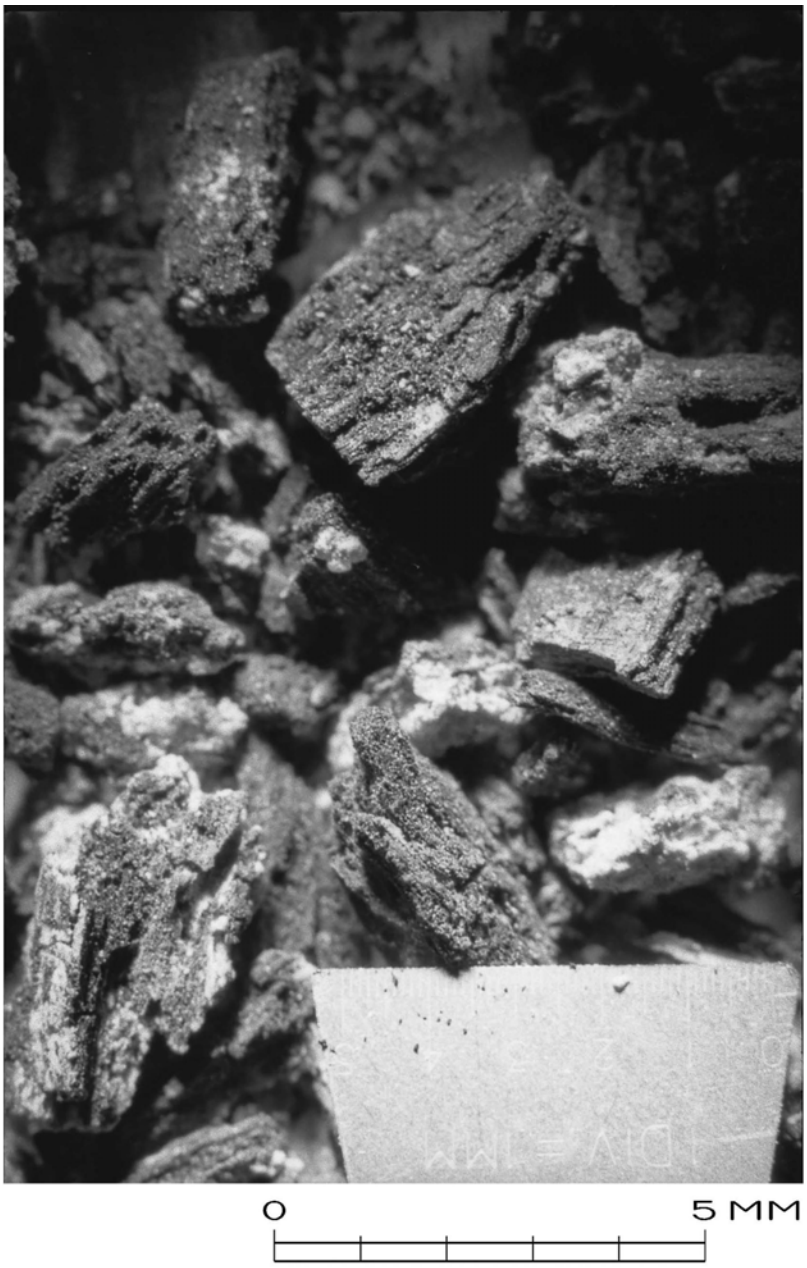


Figure 5.1. Part of Radiocarbon Sample 17 (AA 2831). *Juniperus* sp. charcoal.

GX-17034-II

Uncalibrated age: 9855 ± 310 RCYBP

Calibrated age at 1 sigma:

cal BP age ranges	Area under probability distribution
10,749-10,972	0.182
10,979-11,024	0.032
11,038-11,761	0.708
11,812-11,918	0.078

Field sample number: 30 (assigned *post facto*)

Lab: Geochron

Material assayed: Sediment (1.129 kg), humin fraction

Counting method: unspecified beta counting

Stratum: 2C

Provenience: N111 E101 (92.70-92.65 m), matrix sample from southwest corner

When analyzed: 1991

Remarks: Sediment sample was low in carbon; about 0.17 g of carbon were recovered and counted for two days. No significant humic acids were present (not even enough for recovery and AMS dating; Hal Krueger, personal communication 1991). Measured $\delta\ ^{13}C$ value is –19.0 ‰. Date based on 5570 year halflife and is ^{13}C corrected for fractionation. Date shows excellent agreement with AA 2831.

BETA 73471 (Fig. 5.2)

Uncalibrated age: 10,280 ± 110 RCYBP

Calibrated age at 1 sigma:

cal BP age ranges	Area under probability distribution
11,701-11,710	0.012
11,748-11,861	0.182
11,896-12,339	0.765
12,536-12,568	0.041

Field sample number: 22

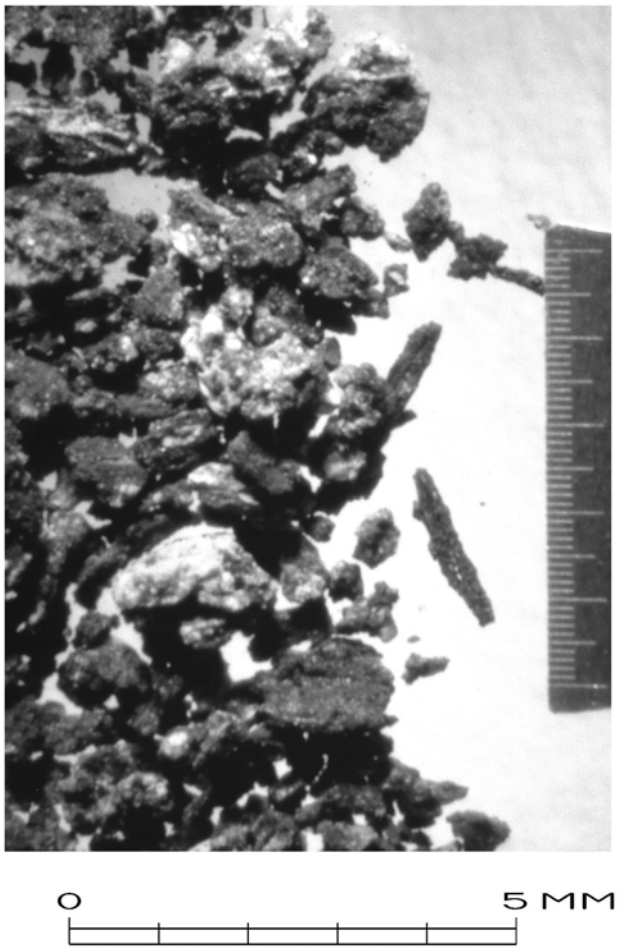


Figure 5.2. Part of Radiocarbon Sample 22 (BETA 73471).

Lab: Beta Analytic

Material assayed: wood charcoal

Counting method: AMS

Stratum: 2C/2B contact

Provenience: N113 E98 (92.55 m)

When analyzed: 1994

Previous publication: Brown (1994)

Remarks: Sample consists of 0. 0947 g of plotted *in situ* wood charcoal combined from three closely spaced locations in the west half of the level at 92.550 and 92.552 m (N113.20 E98.44, N113.55 E98.44, N113.57 E98.15). Location is just south of Feature 5, but about 17 cm above feature level. Associations include a chert heavy percussion flake nearby at 92.578 m. Heavy concentration of microfauna was encountered 13 cm below this sample, at 92.416 m. This sample overlaps at 2 sigma with Tx 3569 but does not quite overlap at 1 sigma, even though they are closely spaced, horizontally and vertically. Fig. 4.36 shows stratigraphy in a nearby profile. Date is based on 5568 year halflife.

GX-18867-AMS

Uncalibrated age: 8926 ± 90 RCYBP

Calibrated age at 1 sigma:

cal BP age ranges	Area under probability distribution
9914-10,091	0.678
10,106-10,189	0.322

Field sample number: 33 (assigned *post facto*)

Lab: Geochron

Material assayed: Sediment (1.650 kg), humin fraction

Counting method: AMS

Stratum: 2B

Provenience: N111 E101 ((2.40-92.35 m), matrix sample from southwest corner

When analyzed: 1994

Remarks: Sediment sample was low in carbon. Measured $\delta\ ^{13}C$ value is –22.1 ‰. Date based on 5570 year halflife and is ^{13}C corrected for fractionation. Date appears too recent. Sample is at same level as Tx 3569 and should date about the same, but does not overlap even at 2 sigma. Sample is also more recent than GX-17034-II, even though it is below it and is also a humin sample; these two samples also do not overlap at 2 sigma.

Tx 3569

Uncalibrated age: 11,550 ± 800 RCYBP

Calibrated age at 1 sigma:

cal BP age ranges	Area under probability distribution
12,640-12,745	0.033
12,786-14,405	0.805
14,662-15,189	0.162

Field sample number: 1

Lab: University of Texas

Material assayed: wood charcoal

Counting method: liquid scintillation

Stratum: 2B

Provenience: Unit 2, Feature 5 (approximately N114.48 E98.33), 92.38 m

When analyzed: 1979

Previous publication: Valastro *et al*. (1988:246)

Remarks: This is the first sample submitted from the site, in the summer of 1979, collected June 26 while blufftop excavations were ongoing. The sample consists of small bits of wood charcoal collected directly from the baked and oxidized surface of the hearth, Feature 5, and the equivalent surface extending a few centimeters to the northeast. Charcoal was intermixed with and closely associated with the extensive microfauna deposit found on the hearth surface and extending to the east and southeast. Sample was very small, assayed by conventional methods and counted three days (Sam Valastro, personal communication), despite which the standard error is very large. This sample is unquestionably in place, not displaced by bioturbation, and has the best cultural associations of any from the site. It is directly associated not with any chert artifacts but with the hearth and microfauna, both believed to be of cultural origin.

AA 2830

Uncalibrated age: 8460 ± 70 RCYBP

Calibrated age at 1 sigma:

cal BP age ranges	Area under probability distribution
9332-9336	0.026
9427-9454	0.233
9464-9532	0.742

Field sample number: 5

Lab: University of Arizona

Material assayed: wood charcoal

Counting method: AMS

Stratum: 2A, upper contact

Provenience: N110 E102 (92.21-92.20 m)

When analyzed: 1988

Remarks: Sample consists of 0.0960 g of plotted *in situ* wood charcoal combined from three closely spaced points in north-central part of level at 92.21-92.20 m. Fragments plotted at N110.13 E102.50, N110.71 E102.41, N110.77 E102.44, directly associated with sandstone clasts, fired clay lumps, rabbit bone, calcined bone from deer-sized animal, and quartzite cobble core plotted in place (resting at 92.17 m) in same level. Sample is also more generally associated with mussel shell-bearing surface in adjacent units and cutbank. A $\delta\ ^{13}C$ value of –25 ‰ is assumed, not measured. Date appears too recent.

Tx 4095

Uncalibrated age: 7770 ± 810

Calibrated age at 1 sigma:

cal BP age ranges	Area under probability distribution
7753-7779	0.010
7785-9545	0.990

Field sample number(s): 10, 23, and 24 combined

Lab: University of Texas

Material assayed: wood charcoal

Counting method: liquid scintillation

Stratum: 2A

Provenience: Sample consists of three combined subsamples, two from excavation units (plotted *in situ*) and one from the cutbank. Sample 10 (2.4131 g) is plotted at N112.98 E99.25 (92.16 m); sample 23 (0.4664 g) is plotted at N113.12 E98.77 (92.15-92.10 m, most *in situ* at 92.13 but some *ex situ* in unit or screen); and sample 24 (0.1055 g) is from the cutbank immediately north of unit N111 E101, elevation not recorded but directly associated with mussel shell zone. Samples collected 12/11/79 and 4/17/80.

When analyzed: 1981

Previous publication: Valastro *et al*. (1988:246)

Remarks: In retrospect, this sample should never have been assayed. Submitted before AMS dating became commercially available, it was an attempt to assemble enough charcoal to date the widespread mussel shell-bearing surface in stratum 2A using conventional analysis. The date obtained is far too recent (the most recent assay of the entire series), most likely because of contamination from inclusion of the cutbank sample. The date overlaps with AA 2830 at 1 sigma, but both are too recent. Even with three combined subsamples, this sample was very small and was counted for 41.6 hours. All three subsamples are closely associated with freshwater mussel shells.

AA 2832 (Fig. 5.3)

Uncalibrated age: 10,070 ± 80 RCYBP

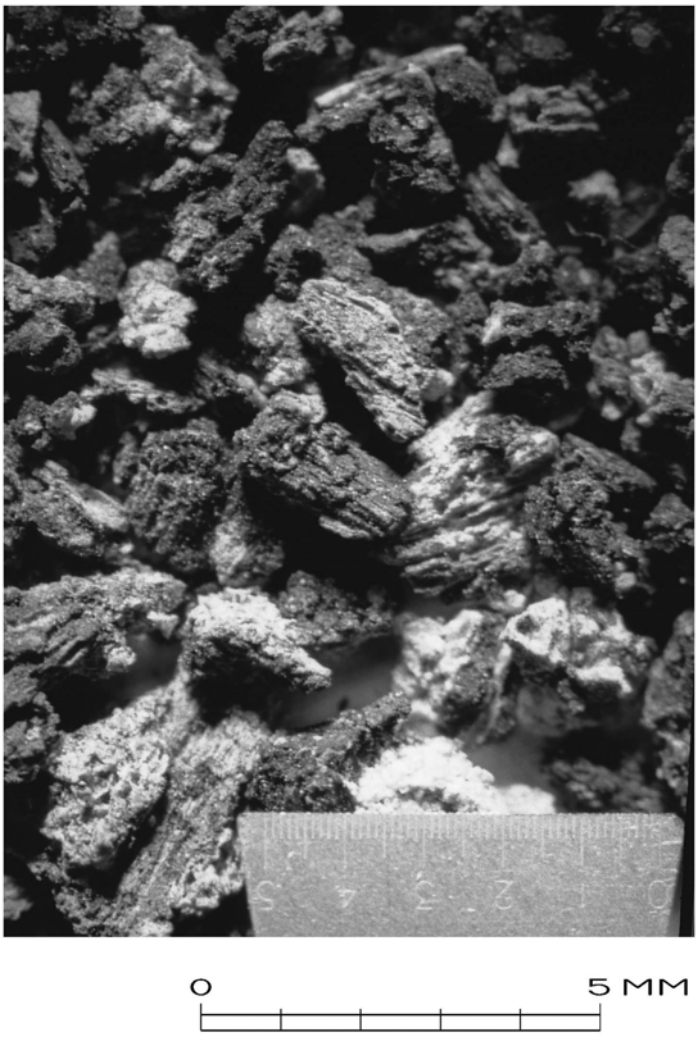


Figure 5.3. Part of Radiocarbon Sample 25 (AA 2832). Note carbonate deposition.

Calibrated age at 1 sigma:

cal BP age ranges	Area under probability distribution
11,303-11,316	0.022
11,338-11,522	0.442
11,536-11,701	0.426
11,711-11,747	0.069
11,863-11,887	0.042

Field sample number: 25

Lab: University of Arizona

Material assayed: wood charcoal

Counting method: AMS

Stratum: 2A

Provenience: Plotted *in situ* at N111.95 E101.67 (92.14-92.11 m)

When analyzed: 1988

Remarks: Sample consists of 0.5318 g of wood charcoal found near north edge of unit and extending over a 3 cm vertical span immediately underneath a cluster of freshwater mussel shells. Sample is also slightly above elevation of origin of Feature 6, which is located on the opposite side of the unit. Some oxidized sandstone and fired clay lumps are associated, as well as some snail shell and the chert core adjacent to Feature 6. Collected 12/10/79. $\delta\ ^{13}C$ value of –25 ‰ is assumed, not measured. Sample is in good agreement with BETA 16979, which is 4 cm deeper in the same unit.

GX-17035-II

Uncalibrated age: 11,305 ± 330 RCYBP

Calibrated age at 1 sigma:

cal BP age ranges	Area under probability distribution
12,963-13,542	0.871
13,676-13,797	0.129

Field sample number: 31 (assigned *post facto*)

Lab: Geochron

Material assayed: Sediment (1.022 kg), humin fraction

Counting method: unspecified beta counting

Stratum: 2A

Provenience: N111 E101 (92.15-92.10 m), matrix sample from southwest corner

When analyzed: 1991

Remarks: Sediment sample was low in carbon; about 0.21 g of carbon were recovered and counted for two days. No significant humic acids were present (not even enough for recovery and AMS dating; Hal Krueger, personal communication 1991). Measured $\delta^{13}C$ value is –18.3 ‰. Date based on 5570 year halflife and is ^{13}C corrected for fractionation. Date seems slightly too old. Sample is from same excavation level as AA 2832 but does overlap with it, even at 2 sigma; sample is just above BETA 16979, but does not overlap with it, even at 2 sigma. Conceivably, this sample might have incorporated some autochthonous organic matter with reservoir effect due to groundwater issuing from the Goliad Formation.

BETA 16979

Uncalibrated age: 10,190 ± 160 RCYBP

Calibrated age at 1 sigma:

cal BP age ranges	Area under probability distribution
11,361-11,384	0.025
11,437-11,470	0.038
11,488-11,500	0.012
11,551-12,153	0.831
12,222-12,305	0.095

Field sample number: 9

Lab: Beta Analytic

Material assayed: wood charcoal

Counting method: AMS

Stratum: 2A

Provenience: Plotted *in situ* at N111.43 E101.58 (92.07 m)

When analyzed: 1986

Remarks: Sample consists of 0.24 g of wood charcoal. Date is based on 5568 year halflife. Sample is in good agreement with AA 2832. Nothing directly associated in this level except some snail shell and lumps of fired clay.

GX-18866-AMS

Uncalibrated age: 8114 ± 93 RCYBP

Calibrated age at 1 sigma:

cal BP age ranges	Area under probability distribution
8791-8796	0.010
8809-8827	0.039
8869-8877	0.017
8902-8910	0.017
8981-9149	0.649
9168-9261	0.268

Field sample number: 32 (assigned *post facto*)

Lab: Geochron

Material assayed: Sediment (2.000 kg), humin fraction

Counting method: AMS

Stratum: 1

Provenience: N111 E101 (91.95-91.90), matrix sample from southwest corner

When analyzed: 1994

Remarks: Measured $\delta\ ^{13}C$ value is –21.0 ‰. Date based on 5570 year halflife and is ^{13}C corrected for fractionation. Date obtained is far too recent for its stratigraphic position and is in conflict with nearly all the stratigraphically higher assays listed above. Sample comes from carbonate-rich zone immediately under stratum 2A, which may have functioned as an aquitard. A well-developed calcrete zone is present in the diagonally adjoining unit. Sample was collected 5-10 cm below the detection elevation for Feature 6, which lies in an adjacent (southeast) corner. No associated material in the immediate level.

SAMPLES SUBMITTED BUT NOT ANALYZED

In September, 1982, I combined three wood charcoal samples and submitted them to Charles Tucek of Radiocarbon, Ltd., a radiocarbon laboratory operating at the time in Lampasas, Texas for conventional assay. In November, Tucek reported that after pretreatment insufficient carbon (less than 0.1 g) remained for assaying, and the attempt was abandoned. In May, 1994, I again contacted Tucek to inquire if the combined sample was still curated somewhere and might be available for AMS analysis, but Tucek confirmed that the sample had been discarded.

The three samples that were combined are as follows:

Field sample number: 15
Provenience: N112 E99 (91.94 m)
Weight: 0.1417 g

Field sample number: 16 (Fig. 5.4)
Provenience: N109 E103 (91.95-91.90 m)
Weight: 1.4635 g

Field sample number: 29
Provenience: N110 E102 (91.95-91.90 m)
Weight: 0.0962 g

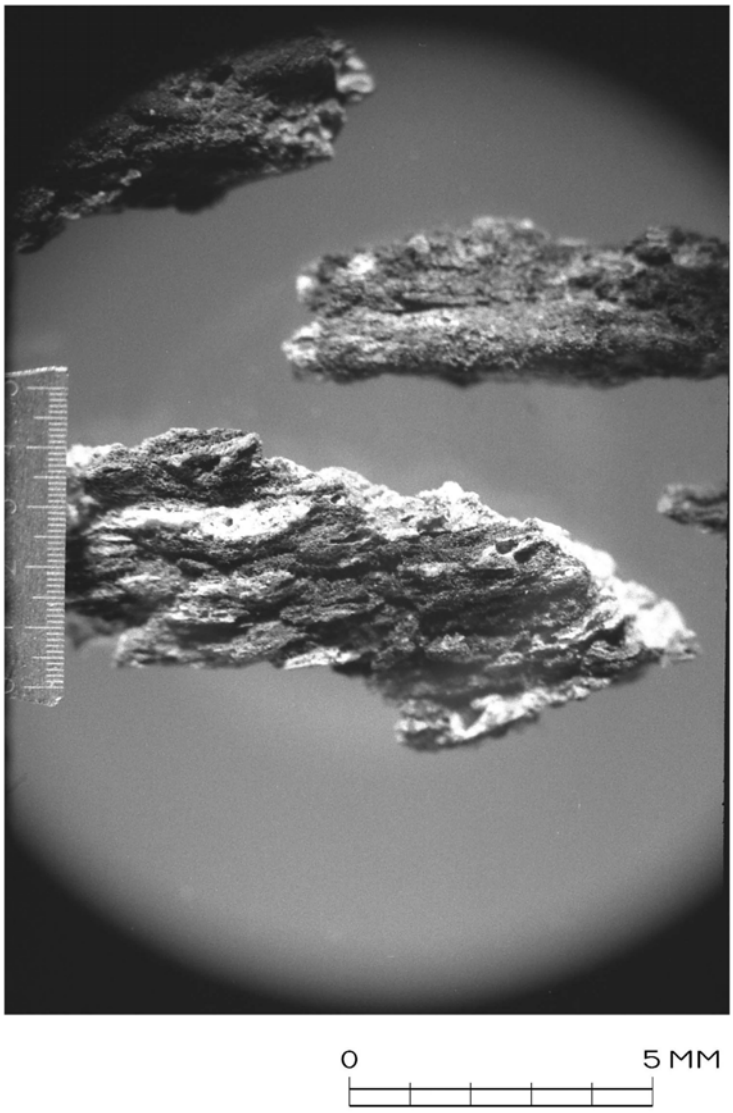


Figure 5.4. Part of Radiocarbon Sample 16. This sample was submitted to Radiocarbon, Ltd. (Lampasas, Texas) but not analyzed. Note carbonate deposition.

EVALUATION OF THE ASSAYS

Archeological sites like Berger Bluff do not yield easily to absolute dating efforts. Relatively slow depositional rates and active water tables can present major challenges (see Jackson and Whitehead 1993 for discussion). A large sample of fixed cultural features (hearths or pits) with associated wood charcoal clearly not moved about by disturbance processes would provide the best data for absolute dating, but during the early history of the site, it was obviously a low-density, limited-use site that was only sporadically visited by short-term occupants, and there are not a great many cultural features. There were evidently other hearths besides Feature 5 (as local informants attest), but Feature 5 is the one for which we have any data. It can be considered a "fixed point" for chronometric purposes, and likewise the wood charcoal (AA 2831) associated with the debris scatter in N109 E96 (stratum 2D) can also be considered a "fixed point." Neither of the two small pits (Features 6 and 7) uncovered in the excavations had directly associated charcoal, although both had some small bits of wood charcoal in the nearby vicinity.

Four sediment humin samples were analyzed in hopes that bulk sediment samples would not be as susceptible to vertical displacement as small fragments of wood charcoal. However, the effort seems largely unsuccessful because the sample age appears substantially controlled by clay content.

Except for animal bone, mussel shell, and snail shell, the only other material suitable for absolute dating consists of small bits of isolated wood charcoal. Besides AA 2831, already discussed, three of these samples (BETA 73471, AA 2830, and AA 2832)

come from light debris scatters that were mapped in place, and for this reason are not considered likely to be fluvially transported fossil charcoal. The fourth (BETA 16979) was not directly associated with any cultural debris.

Inspection of the assays (Table 5.1) shows that there are no wildly discrepant dates – that is, there are no modern, late Holocene or middle Holocene dates – but there are many inversions because there are 4-6 assays that are younger than expected and one that is slightly older than expected. Figures 5.5 and 5.7 show all of the assays, in both uncalibrated and calibrated form, plotted against absolute elevation in meters. Using a 1-sigma standard error, the maximum range of the assays is 6960-12,350 RCYBP, but I will argue that this can be narrowed. I believe the lack of post-early Holocene dates supports my argument in Chapter 4 that bioturbation and vertical translocation of sedimentary fines (or organic matter) ceased as soon as phreatic carbonate cementation was well established.

Nevertheless, there is no consistent age-depth relationship (Figs. 5.5, 5.7). Some of the assays can clearly be rejected on specific grounds. Tx 4095 should be rejected because it probably incorporates a contaminated subsample. Both of the humin samples (GX-18867 and GX-18866) assayed by AMS can be rejected as too young and chiefly reflecting clay content. Possibly GX-17035 should also be rejected as too old and chiefly reflecting clay content. The remaining humin sample (GX-17034) can perhaps be retained because it shows good agreement with AA 2831.

Figure 5.5. Uncalibrated Radiocarbon Assays Plotted Against Elevation: All Assays (*following page*). Assays with GX prefix are on sediment humin, and all others are on charcoal. Midpoints and one-sigma error bars are shown. Boundaries for all climatic periods except the Younger Dryas are approximate.

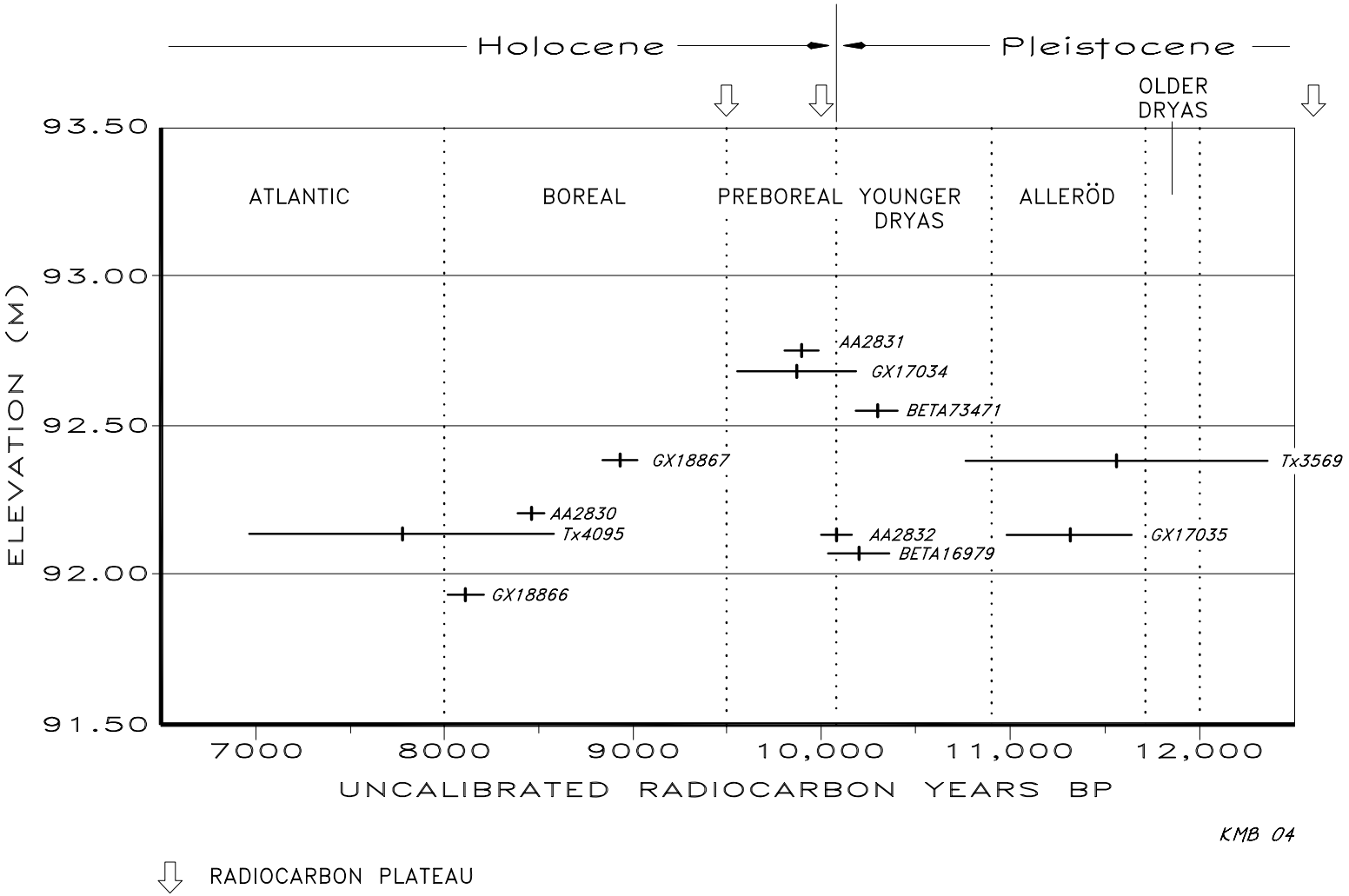

Holocene
Pleistocene
OLDER DRYAS
ATLANTIC
BOREAL
PREBOREAL
YOUNGER DRYAS
ALLERÖD
93.50
93.00
92.50
92.00
91.50
ELEVATION (M)
AA2831
GX17034
BETA73471
GX18867
Tx3569
AA2830
Tx4095
AA2832
GX17035
BETA16979
GX18866
7000
8000
9000
10,000
11,000
12,000
UNCALIBRATED RADIOCARBON YEARS BP
KMB 04
RADIOCARBON PLATEAU

Figure 5.6. Uncalibrated Radiocarbon Assays Plotted Against Elevation: Rejected Assays Omitted (*following page*). This plot shows the six assays considered most representative of the true age of deposition. Assay with GX prefix is on sediment humin, and all others are on charcoal. Midpoints and one-sigma error bars are shown. Boundaries for all climatic periods except the Younger Dryas are approximate.

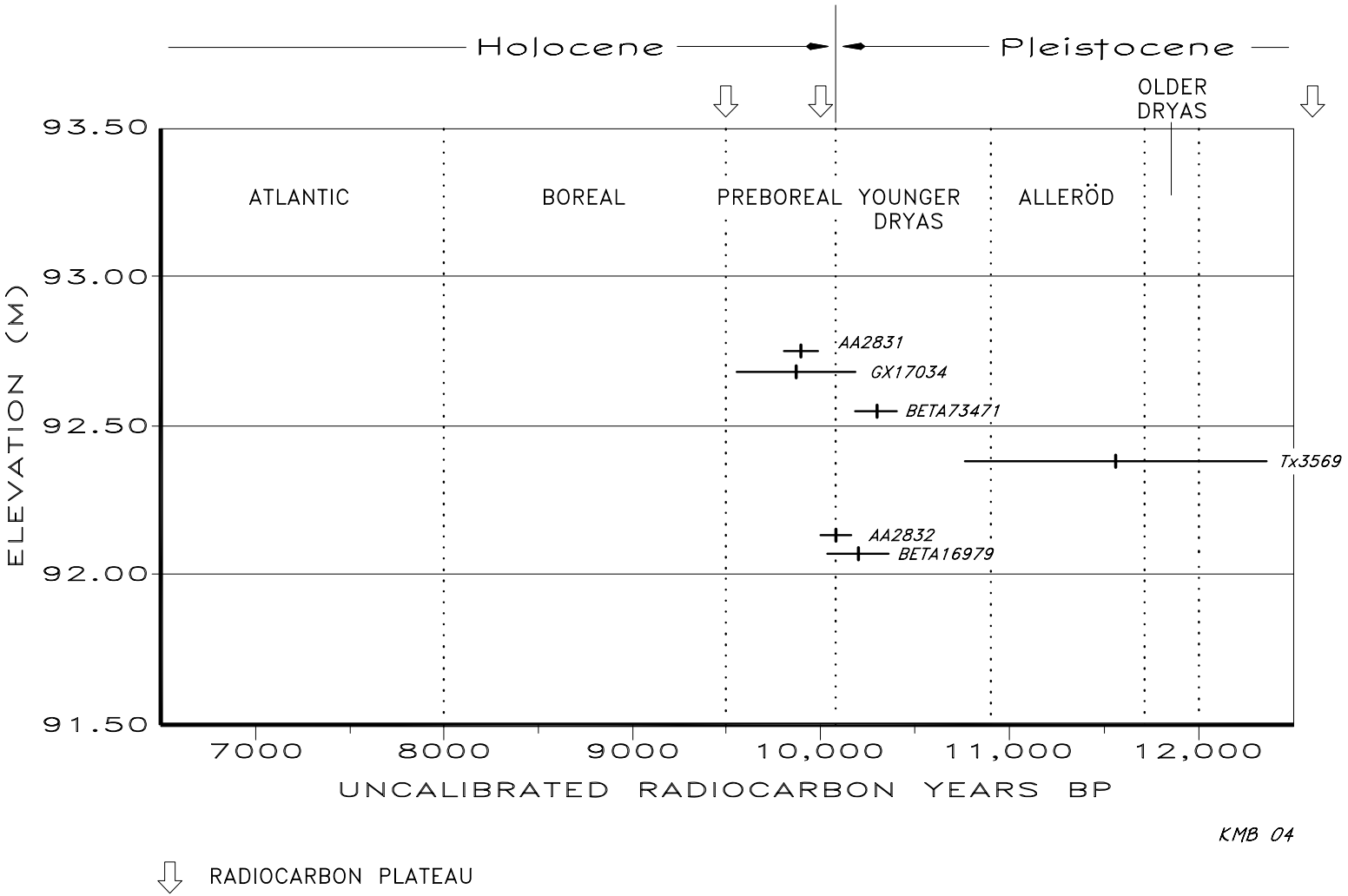

Holocene
Pleistocene
OLDER DRYAS
ATLANTIC
BOREAL
PREBOREAL
YOUNGER DRYAS
ALLERÖD
93.50
93.00
92.50
92.00
91.50
ELEVATION (M)
AA2831
GX17034
BETA73471
Tx3569
AA2832
BETA16979
7000
8000
9000
10,000
11,000
12,000
UNCALIBRATED RADIOCARBON YEARS BP
KMB 04
RADIOCARBON PLATEAU

Figure 5.7. Calibrated Radiocarbon Assays Plotted Against Elevation: All Assays (*following page*). Assays with GX prefix are on sediment humin, and all others are on charcoal. One-sigma spans calibrated using CALIB 4.4 and the INTCAL98 terrestrial database are shown, with calendar years on the bottom axis. Boundaries for all climatic periods except the Younger Dryas are approximate.

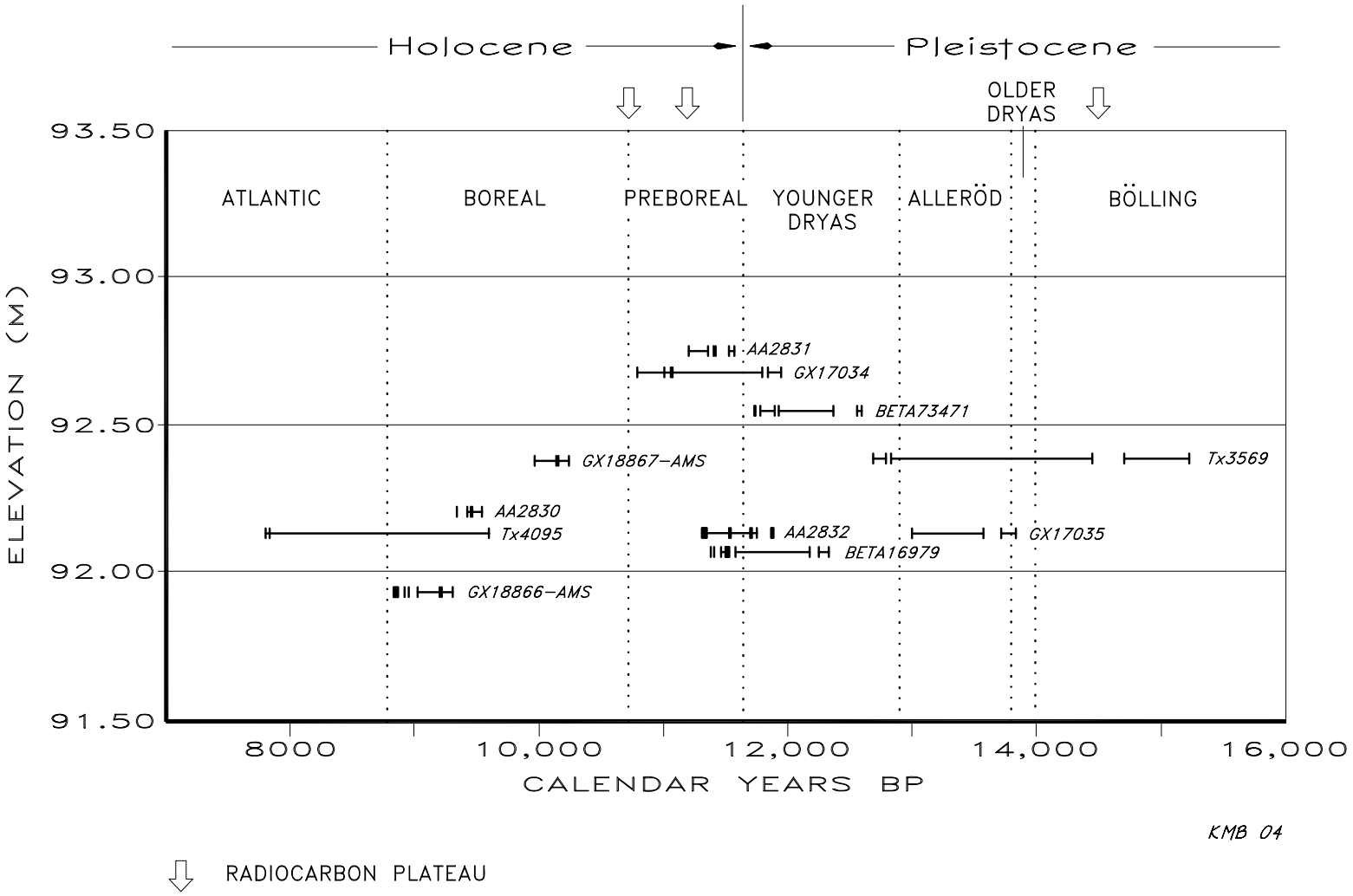
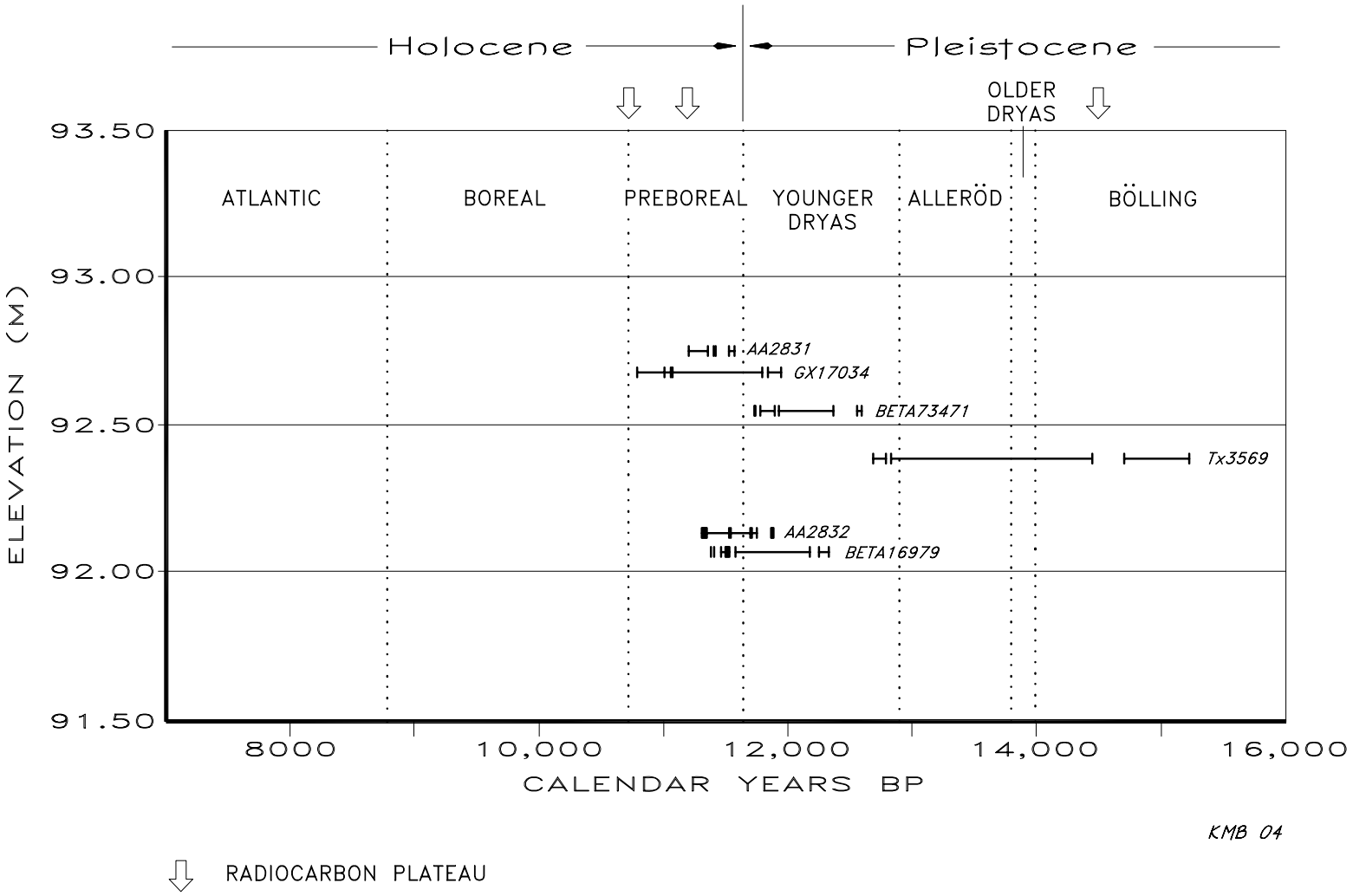

Holocene
Pleistocene
OLDER DRYAS
93.50
93.00
92.50
92.00
91.50
ELEVATION (M)
ATLANTIC
BOREAL
PREBOREAL
YOUNGER DRYAS
ALLERÖD
BÖLLING
AA2831
GX17034
BETA73471
GX18867-AMS
Tx3569
AA2830
Tx4095
AA2832
GX17035
BETA16979
GX18866-AMS
8000
10,000
12,000
14,000
16,000
CALENDAR YEARS BP
KMB 04
RADIOCARBON PLATEAU

Figure 5.8. Calibrated Radiocarbon Assays Plotted Against Elevation: Rejected Assays Omitted (*following page*). This plot shows the six assays considered most representative of the true age of deposition. Assays with GX prefix are on sediment humin, and all others are on charcoal. One-sigma spans calibrated using CALIB 4.4 and the INTCAL98 terrestrial database are shown, with calendar years on the bottom axis. Boundaries for all climatic periods except the Younger Dryas are approximate.


Holocene
Pleistocene
OLDER DRYAS
93.50
93.00
92.50
92.00
91.50
ATLANTIC
BOREAL
PREBOREAL
YOUNGER DRYAS
ALLERÖD
BÖLLING
AA2831
GX17034
BETA73471
Tx3569
AA2832
BETA16979
ELEVATION (M)
8000
10,000
12,000
14,000
16,000
CALENDAR YEARS BP
KMB 04
RADIOCARBON PLATEAU

One other sample, AA 2830, is problematical. There are no grounds to reject it on the basis of provenience or composition (it consists of three tightly clustered subsamples associated with a debris scatter at the upper contact of stratum 2A), but the calculated date of 8460 ± 70 RCYBP is younger than any of the overlying samples. The subsamples are in the same area of the unit as the tree mold that was first detected 30 cm deeper (Fig. 4.56), but no trace of it was detected at the 92.20 m level. This assay should probably be rejected on the basis of conflict with stratigraphically higher assays, although the source of error is unclear.

If GX-18866, GX –18867, GX-17035, Tx 4095, and AA 2830 are eliminated from consideration, the remaining six assays can be seen in uncalibrated (Fig. 5.6) and calibrated form (Fig. 5.8) distributed across the Preboreal, Younger Dryas, and Alleröd to Bölling climatic periods, covering a span of about 3000 uncalibrated years or 4450 calendar years. However, it is unlikely that the true age of Tx 3569 extends into the pre-Younger Dryas period, and it is unlikely that the bench deposits required 4450 calendar years to accumulate. Otherwise, there would have been more evidence of soil development, even allowing for the degree of groundwater saturation in evidence.

My interpretation of the available but somewhat inconsistent radiocarbon data is that the lowest part of the bench sediments visible during fieldwork dates to the Younger Dryas, probably the early part of the Younger Dryas. However, the sediments below 91.28 m were not visible, and the maximum depth and age of the bench sediments are unknown. The middle part of stratum 2D dates to the Preboreal period, based on AA 2831, but there are an additional 80 cm or so of bench sediments above that point remaining undated because there are no assays above 92.75 m. The major environmental

change at the top of the bench remains undated, then, but a very rough plausible estimate for the age of the stratum 3/stratum 4 contact would be about 8500 RCYBP, or midway in the Boreal period, about 1500 years after the end of the Pleistocene.

Because both the upper and the lower part of the bench deposits lack radiocarbon assays, and because the assays in the middle part show major inconsistencies, the estimated age of the bench deposits at 8500-11,000 RCYBP is at best an informed guess-date. This estimate is consistent with the known archeological and biological evidence. There is cultural debris from the deposits, but it is not chronologically or culturally diagnostic. The vertebrate fauna contains one possible extinct species (giant tortoise) and one or two taxa that are slightly extralimital. The snail fauna includes a few extirpated taxa, including at least one taxon (*Valvata tricarinata*) that is a good Pleistocene marker species.

POSSIBLE SOURCES OF ERROR IN CHARCOAL ASSAYS

Three assays on wood charcoal (AA2830, AA 2832, and BETA 16979) produced dates that were somewhat younger than expected, based on stratigraphic position. There are several possible sources of error for charcoal assays. Exhumed fossil charcoal and carbonate contamination have already been mentioned, but these (as well as the "old wood" problem) can be ruled out because they would tend to make the assay too old. Because the principal error trend seems to be for assays to be younger than expected, the most likely sources of error are probably unrecognized bioturbation and contamination by organic acids not completely removed in pretreatment. Contamination by extraneous carbon can occur during chemical processing of AMS samples (Mueller and Muzikar 2002).

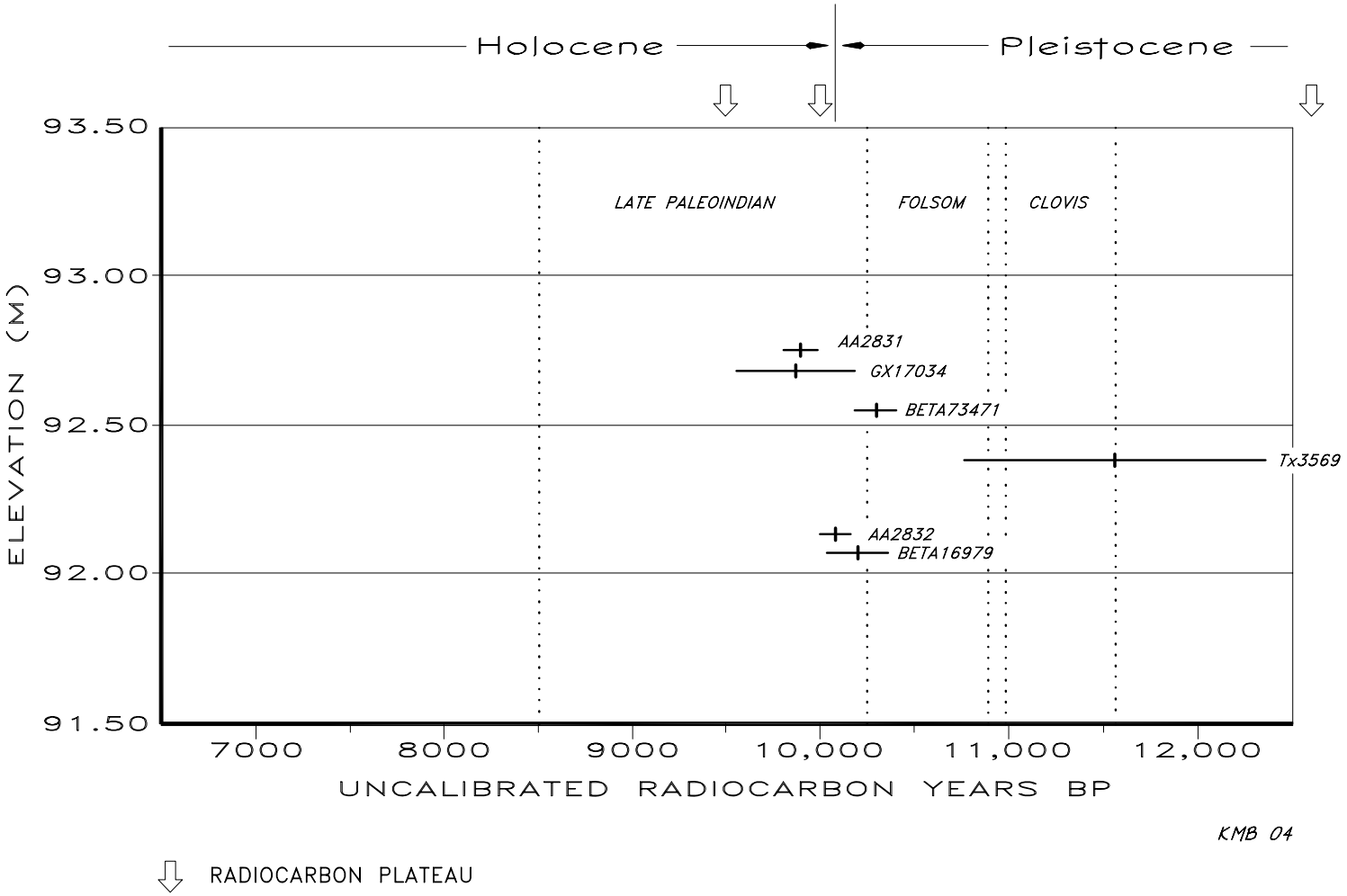
Because AA 2830 was associated with a debris scatter, it was assumed to be in place and not introduced from some higher stratigraphic level. Furthermore, if my estimation of the age of the deposits is correct, it would have to have been displaced downward well over a meter if bioturbation is to explain its anomalously recent date. To a lesser degree, the same arguments apply to AA 2832. BETA 16979 is not directly associated with a debris scatter, but is close to AA 2832 in location and age. All three of these samples come from stratum 2A. The most likely source of error may be recent organic acids that were not completely removed in pretreatment. Standard pretreatment employed by radiocarbon labs uses an acid-alkali-acid (or "AAA") pretreatment consisting of an acid wash to remove carbonates, either an NaOH or KOH alkali bath to remove humic acids, and a final alkali wash to remove absorbed atmospheric CO_2. Goh and Molloy (1979) carried out an extensive study of fulvic and humic acid contamination in buried charcoal samples from New Zealand. They found that charcoal samples had significant quantities of contaminants. The oxidizable organic carbon content of archeological charcoal samples was widely variable (7.3 to 47.5%; Goh and Molloy 1979:Table 2). More humic acid than fulvic acid was found in the samples, and they also found that samples of small pieces of charcoal tended to produce younger assays than samples of large pieces, due to increased surface area and increased potential for adsorption of contaminants [the opposite relationship was found by Blong and Gillespie (1978)]. Alkali-pyrophosphate was found to be an effective pretreatment for removal of these acids, more so than the standard NaOH or KOH pretreatment.

SUMMARY AND CONCLUSIONS FOR CHAPTER 5

There are no radiocarbon assays from the uppermost 80 cm of bench deposits, or from the lowest 60 cm of deposits that were visible during fieldwork, and the maximum depth of the bench deposits is unknown. Eleven assays are available from the middle part of the bench, but several of these (four in particular) are younger than expected, and there are a number of stratigraphic inversions among them. Some assays may have suffered incomplete removal of organic acids by alkali pretreatment. Only two charcoal assays are so securely associated with fixed points (a fired surface or an extensive debris scatter) that vertical displacement of the sample can be completely ruled out. Four different radiocarbon labs, two different assayed substances (charcoal and sediment), and two different assay methods (AMS and conventional beta counter) were used to produce the assays, so it is not surprising that there are some differences between the assays.

For the bench sediments that were visible during fieldwork (a maximum thickness of just over two meters), the most plausible age estimate is a Younger Dryas-Preboreal age, or perhaps about 8500-11,000 RCYP, but with considerable uncertainly resulting from inconsistencies among assays, as well as the lack of assays at the top and base of the bench. Most of the preferred assays fall into the Late Paleoindian or Folsom time spans (Fig. 5.9). The major environmental shift at the top of the bench remains undated, but clearly lies in the early Holocene, based on AA 2831. A rough estimate of about 8500-9000 RCYBP seems plausible, based on that assay and consistent rates of sediment accretion. Thereafter, Coleto Creek experienced a shift in depositional style, stratum 4 began to accumulate, and evidence of spring discharge diminished.

Figure 5.9 (*following page)*. Uncalibrated Radiocarbon Assays Plotted Against Elevation and Cultural Chronology. This plot shows the six assays considered most representative of the true age of deposition and approximate time spans for Late Paleoindian, Folsom, and Clovis complexes. Rejected assays are omitted. Midpoints and one-sigma error bars are shown.


Holocene
Pleistocene
93.50
93.00
92.50
92.00
91.50
ELEVATION (M)
LATE PALEOINDIAN
FOLSOM
CLOVIS
AA2831
GX17034
BETA73471
Tx3569
AA2832
BETA16979
7000
8000
9000
10,000
11,000
12,000
UNCALIBRATED RADIOCARBON YEARS BP
KMB 04
RADIOCARBON PLATEAU

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Chapter 6: Pollen and Macrobotanical Remains

POLLEN SAMPLES

As in most other Texas archeological sites of comparable age, pollen is poorly preserved in the bench sediments at Berger Bluff. While pollen can be well preserved in consistently wet sites (such as peat bogs) or dry sites (such as rockshelters), it is rarely preserved in open sites with alkaline sediments in south Texas (Bryant and Holloway 1985:60), although Bruce Albert has been successful in recovering pollen from terrestrial and marine sites near Victoria and Corpus Christi. Some pollen was recovered from the bench, but the pollen spectrum is severely reduced and biased by diagenesis, and little useful information was recovered. Grain counts are very low, and the taxa identified are mostly those that preserve well or can easily be identified when degraded. Similar results were obtained from two test samples from the upper deposits examined in 1977 by Vaughn Bryant. Bryant examined samples from Test Pit 1, excavated during the initial testing phase at the site. He found no pollen at all in a sample from the 30 cm level, and only "a few grass and oak" from a sample at 120 cm (letter of July 1, 1997, Vaughn M. Bryant to Anne Fox).

In February, 1981, two test samples from unit N113 E98 (at 92.40-92.30 m and 92.15-92.10 m) were sent to Dr. Anne Woosley, Department of Anthropology, Southern Methodist University, to determine if any pollen was preserved. She reported (letter of August 20, 1981) that pollen was present in very low frequencies, and she ran each sample three times, with four slides per sample (for a total of 12 per sample) in an

attempt to increase the grain counts. Table 6.1 lists pollen grain counts only for these two samples, and I have summed the counts for the 12 slides in each sample.

Woosley used the Modified Chevron extraction method (Woosley 1978:Table 5) which omits strong alkali washes and heavy liquid separation, and uses micromesh sieves to produce size-graded subsamples. For the Berger Bluff samples, she used 1 g of sample, dried for 24 hours at 50° C for each preparation instead of the standard 50 g (letter of May 11, 1982).

Table 6.1. Pollen Recovery from N113 E98 (Woosley).

	Pinus	*Quercus*	Gramineae	Compositae	Leguminosae	Row totals
92.40-92.30 m	28	25	33	0	11	97
92.15-92.10 m	61	38	0	13	0	112
Column totals:	89	63	33	13	11	209

In addition to the pollen grains, many spores were also present on the slides. In fact, over 5200 spores were counted from the 92.40-9.30 m sample, and over 6300 from the 92.15-92.10 m sample, representing several different types (*Sphagnum, Lycopodium, Pteridium, Botrychium, Tilletia, Osmunda, Dicranum, Lycoperdon* and other types; letter of September 1, 1981). This was a wholly unexpected finding. The fact that the spores greatly outnumber the pollen grains (by a ratio of 55:1) suggests they could be recent contaminants, and it appears possible that the spores (and possibly some of the pollen grains) are present because of some sort of contamination of the pilot samples. *Tilletia* is wheat rust, and is thought to be a historic introduction.

After these results were received, a single column of 26 pollen samples was submitted to Richard G. Holloway of Texas A&M University in October, 1981, and the analysis results for 24 samples were received in April, 1982. Pollen samples were extracted from the "phytopol" samples collected from the southwest corner of units N109 E103 and N110 E102 (Fig. 3.4). The collection procedure is described in Chapter 3; a total of 25 samples came from the matrix column in the southwest corner of N110 E102, and a 26th sample was added from N109 E103 to increase the column height. Holloway used a pollen extraction procedure that differs from that used by Woosley. His protocol is as follows:

> Fifty milliliters of sample were placed in a centrifuge tube. DMSO (Di-methyl sulfoxide, 99%) was added to cover the sediment. The solution was heated in a hot water bath for one hour. The material was then screened through 200 μm mesh screen and treated successively with HCl and HF. After washing with water, the residue was treated with zinc chloride (1.99-2.00 S.G.) and acetolyzed. After acetolysis the residue was dehydrated with an ethanol series and transferred to 1000 cs silicon oil with butanol (letter of April 26, 1982).

Table 6.2 lists the results obtained by Holloway.

Several things are apparent from comparing these two tables. Woosley was able to obtain much higher grain counts for her two samples by processing larger quantities of sediment and preparing 12 slides per sample. Holloway found very few spores and only two grains of pine pollen, in contrast to Woosley's samples, where pine was the most abundant arboreal taxon and large numbers of spores were present. Oak and composites were found in both analyses. There is no evidence of contamination in the samples I sent to Holloway.

Table 6.2. Pollen Recovery from N109 E103 and N110 E102 (Holloway).

Unit	Level	Pollen concentration (grains/ml)	Inventory of palynomorphs
N109 E103	92.95-92.90	48	1 *Pinus*, 31 h-s Compositae, 1 fungal spore
N110 E102	92.90-92.80 upper	0	no pollen
N110 E102	92.90-92.80 lower	9	2 indeterminate
N110 E102	92.80-92.75	2	1 Cheno-Am
N110 E102	92.75-92.70	0	no pollen
N110 E102	92.70-92.65	0	no pollen
N110 E102	92.65-92.60	3	1 l-s Compositae, 1 trilete spore
N110 E102	92.60-92.55	9	2 *Quercus*
N110 E102	92.55-92.50	9	3 l-s Compositae, 1 fungal spore
N110 E102	92.50-92.45	3	1 indeterminate
N110 E102	92.45-92.40	1	1 *Carya*
N110 E102	92.40-92.35	?	no results received
N110 E102	92.35-92.30	0	no pollen
N110 E102	92.30-92.25	0	no pollen
N110 E102	92.25-92.20	0	no pollen
N110 E102	92.20-92.15	0	no pollen
N110 E102	92.15-92.10	29	2 *Quercus*, 1 *Populus*, 3 l-s Compositae, 2 indeterminate, 2 fungal spores
N110 E102	92.10-92.05	11	1 *Quercus*, 1 fungal spore
N110 E102	92.05-92.00	47	1 *Quercus*, 6 l-s Compositae, 3 indeterminate, 1 monolete spore, 1 fungal spore
N110 E102	92.00-91.95	18	4 *Quercus*, 1 *Salix*, 1 Liguliflorae, 4 fungal spores
N110 E102	91.95-91.90	?	no results received
N110 E102	91.90-91.85	8	1 *Quercus*, 1 l-s Compositae, 1 h-s Compositae, 2 indeterminate, 2 fungal spores
N110 E102	91.85-91.80	?	not submitted
N110 E102	91.80-91.75	?	not submitted
N110 E102	91.75-91.70	10	1 *Pinus*, 1 *Quercus*, 1 *Populus*, 1 Indeterminate, 1 fungal spore
N110 E102	91.70-91.65	8	1 *Quercus*, 1 *Liquidambar*, 1 Cheno-Am, 1 indeterminate, 2 fungal spores
N110 E102	91.65-91.60	14	1 *Quercus*, 1 indeterminate
N110 E102	91.60-91.55	15	2 *Quercus*, 7 h-s Compositae, 1 fungal spore

Notes: l-s = low-spined Compositae; h-s = high-spined Compositae. Samples from 92.40-92.35 m and 91.95-91.90 m submitted but no results received. Sample from N109 E103 comes from lower part of the 93.14-92.90 m level. Second and third samples listed come respectively from the upper and lower 5 cm of the 92.90-92.80 m level.

Holloway's data show that pollen is very poorly preserved, but is better preserved below 92.15 m (the upper contact for stratum 2A) than above, probably because the lower levels were more consistently below the water table and less subject to seasonal wetting and drying cycles. Alkaline sediments (pH above 6.0), oxidizing conditions, and frequent wet-dry cycles tend to result in severe pollen degradation and taphonomically biased assemblages (Holloway 1989; Bryant *et al*. 1994). Hunt (1994:116) observes that

> In general, palynomorphs resistant to microbial degradation and oxidation (such as fern spores, Compositae pollen and bisaccate gymnosperm pollen) tend to survive in the fluvial environment far longer than less resistant forms…. *Pinus* and other bisaccate pollen is often 'over-represented' in waterlaid sediments… as are Compositae pollen and fern spores… The same taxa are also very resistant to decomposition in soil profiles.

There is no reason to interpret the anomalous pollen results from N113 E98 as any kind of indication of disturbance. As the west wall profile (Fig. 4.36, 4.37) shows, there are some small sand pockets in stratum 2C, but the levels from which the pollen samples were collected are undisturbed. It is also worth noting that discrepancies between these same two analytical approaches also occurred at Joe Pool Lake. The reader is urged to read Holloway (1988) for further elaboration.

Little can be said about the local or regional vegetation based on these data. Isolated grains of oak (16), pine (2), cottonwood (2), willow (1), *Carya* (1, probably pecan, rather than hickory), and sweetgum (1) were recovered by Holloway. High-spined composites produced 45 grains, low-spined composites 14 grains, Cheno-Ams 2 grains, and Liguliflorae, 1 grain. Although not normally thought of as being part of the local vegetation, there are actually isolated pines (single trees or groves, Fig. 1.20) in the area now, and the nearest pine tree I am aware of that appears to be naturally occurring is

located on Sandies Creek, just south of Leesville, about 32.5 km north-northwest of the head of the Berger Bluff catchment. Loblolly pine should be well-suited edaphically to the sandy Miocene soils in the catchment, requiring only enough moisture and low enough temperatures to survive. In its core area, it can persist on as little as 5.6 cm of precipitation in January and 4.7 cm in July (see discussion in Chapter 1), which is roughly equivalent to modern conditions in the catchment (Figs. 1.14, 1.15). Youngman (1965:111) found that loblolly pine seedlings from isolated stands in south-central Texas were better adapted to dry conditions than east Texas seedlings. When pine is not a part of the local vegetation, its pollen is often ascribed to long-distance transport, and indeed Hall found pine pollen throughout his 320 km-long transect of pollen traps from the Sangre de Cristo Mountains of New Mexico out onto the Llano Estacado near Dalhart (Hall 1990:Fig. 15), demonstrating that airborne pine pollen can travel hundreds of kilometers. Pine pollen was also recovered by Albert (1999:Table 1) in both modern and early historic context from Mission Rosario in Goliad County. It has also been found elsewhere in prairie habitats where there are no native pine trees (Hall 1992). Nevertheless, there also exists the untested possibility that loblolly pine might have been more extensive in the past. Although it appears to be at or beyond its environmental tolerance limits now, greater precipitation and lower temperatures in the Younger Dryas and early Holocene might have allowed it to expand its range, and the isolated loblolly pines now seen from Gonzales County to the northeast (Youngman 1965:Fig. 1) might be relicts of a more extensive population similar to the Lost Pines of Bastrop County. The two grains of pine pollen found by Holloway offer no way to test this proposition, however. The single grain of sweetgum (Liquidambar) pollen also represents a taxon that is no longer a part of the local vegetation, but isolated grains of sweetgum pollen in early contexts at South Soefje Bog, Hershop Bog, Winston's Cave, Friesenhahn Cave, the

Richard Beene site, and the Devil's Mouth site (see discussion at the end of Chapter 2) also suggest the possibility that sweetgum might have been a minor component of floodplain forests in the region in the Younger Dryas and early Holocene.

PLANT MACROFOSSIL REMAINS

In October, 1981, nine very small charcoal samples were submitted to Phil Dering for possible taxonomic identification (Table 6.3). These were all collected as potential radiocarbon samples. Dering was only able to identify four of these, consisting of elm, *Carya* (probably pecan), oak, and *Juniperus* (probably eastern red cedar). Also listed are two other macrofossils that I identified myself.

Table 6.3. Plant Macrofossils from the Bench Deposits.

Radiocarbon sample number	Unit	Elevation	Identification
16	N109 E103	91.95-91.90	no ID
E	N110 E102	91.95-91.90	no ID
2	N111 E101	92.65	*Ulmus* sp. (elm)
3	N111 E101	92.65-92.60	*Carya* sp. (pecan/hickory_
B	N111 E101	92.20-92.15	no ID
7	N112 E99	92.38	*Quercus* sp. (oak)
17 (AA 2831)	N109 E96	92.75	*Juniperus* sp. (E. red cedar?)
D	N109 E96	92.45-92.40	no ID
C	Unit 2	Under F-5	no ID
(none)	N113 E98	92.20-92.15	Unidentified monocot (?)
(none)	N109 E96	92.75-92.70	Unidentified tree resin or sap

In addition to the nine samples submitted to Dering, there are many more extremely small charcoal fragments inventoried from various excavation levels, but not submitted because they are too small or poorly preserved for identification.

UNIDENTIFIED CHARRED MONOCOT (?)

A small patch of charred plant material was recovered from unit N113 E98 (92.20-92.15 m), extracted from an un-numbered radiocarbon sample that was collected on April 17, 1980. It resembles a small fragment of charred grass, sedge, or rush-like material that had been trampled into wet calcareous mud and somehow preserved (Fig. 6.1). I identified it as a possible monocot, and in November, 1996, Phil Dering examined it under magnification up to 70X and confirmed the identification.

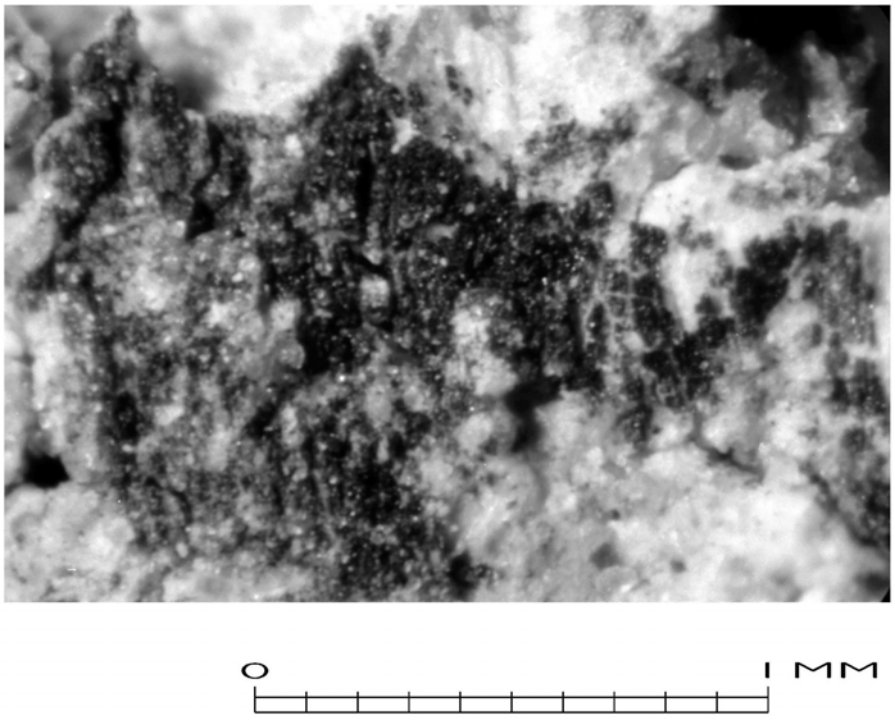

Figure 6.1. Unidentified Charred Monocot. Note vertical grain of charred grasslike material embedded in calcareous mud.

UNIDENTIFIED TREE RESIN OR SAP

A small fragment that appears to be hardened tree resin or sap was recovered from unit N109 E96 (92.75-92.70), bulk matrix, coarse fraction. Examination under magnification reveals that it has conchoidal fracture patterns, surface cracking and white secondary carbonate deposition, indicating that it is probably contemporary with the bench deposits and not a recent intrusive specimen. There are any number of species now or perhaps formerly present in the Berger Bluff catchment that could produce tree resin like this, including various members of the Fabaceae or Cupressaceae (mesquite, eastern red cedar, pine, cypress, sweetgum, various acacias and other species). Sap production is especially likely when insects attack these species. Amber is also known from Eocene deposits in the region, but this specimen does not appear to be amber.

A second piece of resin was also recovered from N109 E96 (92.55-92.50) from the 1/4-inch mesh screen (lot B-134), but is believed to be intrusive, and consequently is not listed in Table 6.3. It is a very small reddish brown piece with no weathering or carbonate deposition, and could very well represent resin from the yellow pine lumber used in the fieldwork for screening sticks or excavation screens. It is considered a contaminant.

HACKBERRY SEED COATS

The calcareous, biomineralized endocarps of hackberry (*Celtis* sp.) are common occurrences in south and southwest Texas archeological sites. Sugarberry (*Celtis laevigata*) and granjeno *(Celtis pallida*) are both reported from the reservoir area (Espey,

Huston & Associates 1976:Table 2-18), and Lindheimer hackberry (*Celtis lindheimeri*) is also found in south Texas. The endocarps are mostly calcium carbonate (Cowan *et al.* 1997:269) and will dissolve in hydrochloric acid. They also contain minor amounts of silica, potassium, magnesium, and sulfur. Examples from the bench are usually medium gray or beige in color and fairly well preserved, although they are brittle and will easily divide into halves or shatter into small fragments. Some rodents will cache these seeds, and caches are sometimes found in archeological sites, but none were found in the bench deposits. Instead, all examples were isolated finds and are believed to be natural, "background" components of the floodplain sediments. Table 6.4 shows hackberry seed finds from the bench deposits, mostly from the westernmost units. Specimen counts are not indicated because fragmentation makes it difficult to determine minimum numbers of individuals.

Table 6.4. Hackberry Seed Coats from the Bench Deposits.

Lot number	Unit	Level	Stratum
B-99	N112 E99	92.15-92.10	2A
B-109	N113 E98	92.14-92.13	2A
B-125	N109 E96	93.08-93.00	2D
uncatalogued	N109 E96	92.85-92.80*	2D
uncatalogued	N109 E96	93.08-93.00 bulk matrix	2D
B-129	N109 E96	92.80-92.75	2D
uncatalogued	N109 E96	92.75-92.70 bulk matrix	2D
uncatalogued	N109 E96	92.70-92.65 bulk matrix	2D
uncatalogued	N109 E96	92.55-92.50 bulk matrix	2C/2D
uncatalogued	N109 E96	92.50-92.45 bulk matrix	2C
B-136	N109 E96	92.45-92.40	2C
B-137	N109 E96	92.40-92.35	2B/2C
B-144	N109 E96	92.20-92.15	2A
uncatalogued	N109 E96	92.15-92.10 bulk matrix	2A
uncatalogued	N109 E96	92.05-92.00 bulk matrix	2A
B-148	N109 E96	92.05-92.00	2A

* Specimen found inside snail shell; accidentally destroyed.

SUMMARY AND CONCLUSIONS FOR CHAPTER 6

Pollen and plant macrofossils are poorly preserved in the bench deposits. Pollen has probably been affected by seasonal wetting and drying, especially in the upper part of the section, by microbial attack, and by the alkalinity of the sediments. It is taphonomically biased in favor of taxa that resist decay. Charcoal was frequently observed or recovered in the excavations, but the fragments are so small that taxonomic identification was rarely possible. Most of the taxa recognized by Dering and Holloway (oak, cottonwood, willow, pecan, elm, and ?eastern red cedar) are common in the area today. Isolated grains of pine and sweetgum might represent wider distributions of these taxa during the Late Pleistocene/early Holocene, or might simply represent long-distance wind transport. Composites are usually indicators of disturbed habitats, but they also tend to resist decay better than many other taxa.

The source for large numbers of spores in samples studied by Woosley is unknown, but the results are not accepted as analytically valid.

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Chapter 7: Diatoms and Freshwater Sponge Spicules

INTRODUCTION

Diatoms are microscopic, single-celled, photosynthetic algae with silica cell walls that may be preserved in archeological deposits. Formerly considered members of the plant kingdom, they are now often classified (along with other organisms such as kelp and mildew) in the kingdom Chromista. They are also members of the phylum Bacillariophyta. Although most archeologists probably think of diatoms and other forms of algae as aquatic organisms, they also live in terrestrial environments that are sufficiently damp, and in fact about half of the diatoms counted in the bench samples are from species that can be found in either submerged or terrestrial habitats. Aerophilic species are motile and can move in response to light sources (Winsborough 2001:114). Aquatic species are found in benthic (bottom-dwelling), epiphytic (attached to plants) or planktonic (free-floating) forms. A wide range of environmental variables has been investigated as possible controls on abundance and assemblage composition in aquatic habitats (both fossil and modern), chiefly water chemistry (pH, salinity, dissolved organic and inorganic carbon, nitrogen, phosphorus, magnesium, iron, and sulfide content) and physical properties (water temperature, velocity and turbulence, depth; Moser, MacDonald and Smol 1996:31-34; Battarbee *et al*. 2001:164-168). Patrick (1977) provides a very comprehensive review.

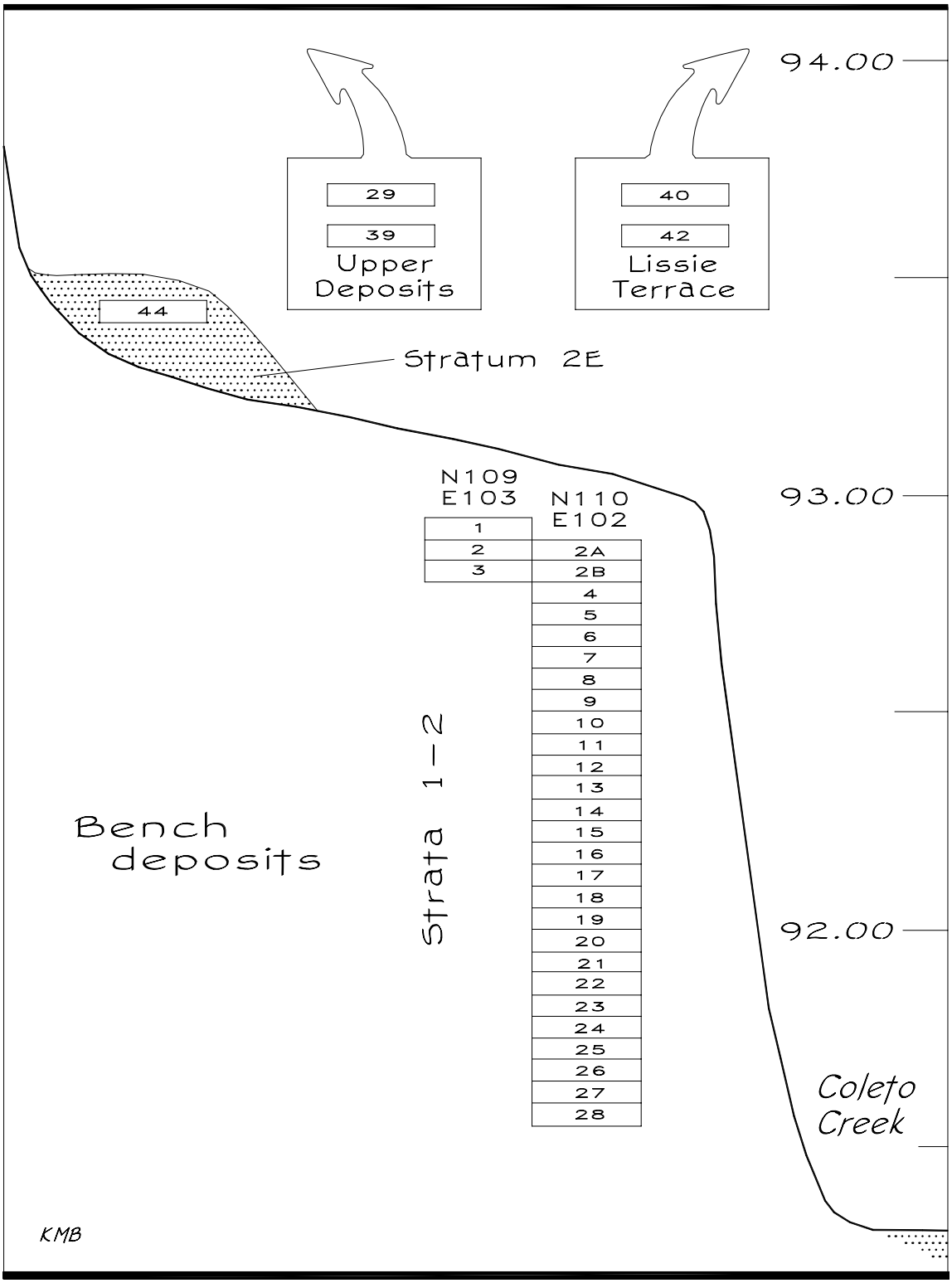
Freshwater sponges are sessile, multi-celled, invertebrate members of the animal kingdom (phylum Porifera, family Spongillidae) and are entirely confined to freshwater aquatic habitats. They are mentioned in this chapter because their decomposition also produces microscopic siliceous bodies that may preserve well in alluvial sediments. They

probably occur in many streamside archeological sites, but are usually overlooked. Freshwater sponge spicules from Berger Bluff were not systematically studied, but I noted their presence and condition both in sediment thin sections and in raw sediment samples examined microscopically on glass slides (see Chapter 4). Sponge spicules also appear (along with phytoliths) on the diatom slides, where their presence was noted but not tabulated. They have also been reported from two sites (41 GD 21 and 41 GD 21A) on Sulphur Creek in the western part of Coleto Creek Reservoir (Robinson 1979). Sponge spicules will receive only brief discussion here. Plant phytoliths and chrysophyte cysts were also noted on the diatom slides, but not identified or tabulated. Chrysophytes are golden brown algae in the class Chrysophyceae (mostly freshwater). Texas has at least 33 species (Wujek, Wee and Van Kley 2002). Cysts are spherical, siliceous resting stages which may be preserved in sediments (Cohen 2003:297-298; Nicholls and Wujek 2003:Fig. 2; Wilkinson, Hall and Smol 1999:18; Zeeb and Smol 2001).

DIATOM SAMPLING AND ANALYSIS METHODS

Altogether 31 small sediment samples from the bench deposits were submitted for diatom analysis to Barbara Winsborough of Winsborough Consulting (Table 7.1). Twenty-seven of these samples form a continuous column (92.90 to 91.55 m) extracted from matrix samples in the southwest corner of unit N110 E102. These are supplemented by three more samples (92.95 to 92.80 m) from the southwest corner of N109 E103, added to give better representation at the top of the bench (Fig. 7.1). Figure 3.4 shows how these subsamples were collected from the matrix samples. One more sample (number 44) was extracted from the 93.45-93.40 m geological sample in the cutbank in order to sample stratum 2E. Because the 92.80-92.80 m level in N110 E102 is a 10 cm level, separate samples were submitted from the upper (2A) and lower (2B) halves of the level (Fig. 7.1). Unfortunately, there are no samples from stratum 3. A total of 7882 diatom cells was counted from these 31 samples.

Figure 7.1 (*following page*). Diatom Samples. Schematic cross-section, vertically exaggerated, through the bench deposits. Vertical scale is absolute elevation in meters. Note that sample 2 approximately duplicates sample 2A in elevation, and sample 3 approximately duplicates sample 2B. Samples 40 and 42 were collected from the Lissie terrace exposure upstream from the site. Stratum 2E is actually exposed along the cutbank downstream, but in this schematic view is shown pushed back from the edge in order to keep the relative elevation of the sample consistent. See Fig. 4.22 for the actual position of this stratum and the sample block.


94.00
93.00
92.00
29
39
Upper Deposits
40
42
Lissie Terrace
44
Stratum 2E
N109 E103
N110 E102
1
2
3
2A
2B
4
5
6
7
8
9
10
11
12
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23
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26
27
28
Strata 1–2
Bench deposits
Coleto Creek
KMB

Table 7.1. Comprehensive List of Diatom Samples.

Sample	Unit	Level	Comments
Samples from the bench deposits			
44	Cutbank	93.45-93.40	No sponge spicules or phytoliths, almost no diatoms, sample is bacteria-rich
1	N109 E103	92.95-92.90	Sponge spicules, phytoliths
2A	N110 E102	92.90-92.80 upper	Few diatoms, many of them broken
2B	N110 E102	92.90-92.80 lower	A few broken spicules, phytoliths and vascular plant fragments
4	N110 E102	92.80-82.75	Whole diatoms, mostly soil species, but diluted in sample; sponge spicules, pollen and phytoliths present
5	N110 E102	92.75-92.70	A few broken spicules, phytoliths and vascular plant fragments
6	N110 E102	92.70-92.65	A few sponge spicules, phytoliths
7	N110 E102	92.65-92.60	Sponge spicules and phytoliths
8	N110 E102	92.60-92.55	Sponge spicules and phytoliths
9	N110 E102	92.55-92.50	Sponge spicules and phytoliths
10	N110 E102	92.50-92.45	Sponge spicules and phytoliths
11	N110 E102	92.45-92.40	Phytoliths present
12	N110 E102	92.40-92.35	Diatoms, soil and aquatic; sponge spicules, pollen, phytoliths present
13	N110 E102	92.35-92.30	Sponge spicules and phytoliths
14	N110 E102	92.30-92.25	Broken spicules, phytoliths, and chrysophyte cysts
15	N110 E102	92.25-92.20	Spicules, phytoliths, chrysophyte cysts; diatoms are mostly fragments
16	N110 E102	92.20-92.15	Sponge spicules and phytoliths
17	N110 E102	92.15-92.10	Spicules, phytoliths, chrysophyte cysts
18	N110 E102	92.10-92.05	Spicules, phytoliths, chrysophyte cysts; diatoms are mostly fragments
19	N110 E102	92.05-92.00	Sponge spicules and phytoliths
20	N110 E102	92.00-91.95	Spicules abundant, phytoliths, many whole diatoms, including aquatic species
21	N110 E102	91.95-91.90	Spicules abundant, phytoliths, many whole diatoms, including aquatic species
22	N110 E102	91.90-91.85	Spicules, phytoliths, many whole diatoms
23	N110 E102	91.85-91.80	Sponge spicules and phytoliths
24	N110 E102	91.80-91.75	Spicules, phytoliths, chrysophyte cysts; many whole diatoms
25	N110 E102	91.75-91.70	Spicules, phytoliths, chrysophyte cysts; many whole diatoms

(continued on next page)

(Table 7.1, continued)

Sample	Unit	Level	Comments
25	N110 E102	91.75-91.70	Spicules, phytoliths, chrysophyte cysts; many whole diatoms
26	N110 E102	91.70-91.65	Spicules, phytoliths, chrysophyte cysts
27	N110 E102	91.65-91.60	Spicules, phytoliths, chrysophyte cysts; diatoms mostly fragments
28	N110 E102	91.60-91.55	Diatoms (soil), sponge spicules, pollen, phytoliths
Additional samples from the bench deposits			
2	N109 E103	92.90-92.85	A few corroded spicules, phytoliths
3	N109 E103	92.85-92.80	A few spicules, phytoliths
Samples from the upper deposits			
29	N97 E96	99.75	Sterile
39	N97 E96	97.75	Sterile
Samples from the Lissie terrace, column 1			
40	Sample 1-1		Sterile
42	Sample 1-3		Spicules, few phytoliths or diatoms

Four more diatom samples were submitted for comparative purposes, and three of them proved to be sterile. Two of these (samples 29 and 39) were extracted from the southwest corner wall of the large excavation block in the upper deposits. These come from the west wall of unit N97 E96 at 99.75 m and 97.75 m, from strata 5 and 4 respectively (black sample boxes in Fig. 4.61). Joan DeCosta and I collected these from the standing wall of the open excavation on April 17, 1981. Both of these samples were sterile, producing no diatoms at all. Winsborough noted that sample 39 (97.75 m) also lacked phytoliths, pollen, or sponge spicules. The reason is unknown though it might somehow relate to late Middle and Late Holocene local aridity.

The other two samples (samples 40 and 42) were collected from the Lissie terrace cutbank, upstream from the site. These come from stratigraphic section 1 (samples 1-1 and 1-3; Fig. 4.13). Of the two, the upper sample, number 40, was also sterile. The lower sample, number 42 (= field number 1-3) produced a diatom assemblage somewhat different from that seen in the bench deposits.

Altogether, 35 samples from these different contexts were analyzed. These 35 samples were analyzed in three separate batches. The first batch (February, 1992) was a pilot study of six samples designed to discover if diatoms were preserved at the site, and if they would have any diagnostic value. The second batch (December, 1992) added six more samples. The final batch (February, 1998) added 23 more samples and completed the columns.

Barbara Winsborough describes the processing protocol as follows:

> The material was treated with hydrogen peroxide and nitric acid to oxidize the organics and remove soluble minerals. Permanent glass slides were made using HYRAX, a resin with a high refractive index. Slides were scanned at 1500X. Because the samples were sparsely diatomaceous, the entire slide was scanned,

> and both whole cells and fragments large enough to be recognized were counted. The presence of phytoliths, sponge spicules and any other biogenic material was recorded along with the diatoms (Winsborough 1998a:2).

It should be noted that the concentration of diatoms in the sediments and the number of diatoms counted per slide both vary widely. Two sets of slides were prepared from the processed samples; Winsborough retained one, and the other is to be curated with the site collections.

In addition to the archeological samples, a series of contemporary comparative samples was collected from the Berger Bluff catchment in 1997 and 1998. Twenty-one localities (diatom sampling sites D-1 through D-21) in the counties of Karnes, De Witt, Goliad, and Victoria were sampled. Where possible, from each site at least one small soil sample, a 2 cc bottom water sample, and a 2-quart water column sample were collected and delivered to Barbara Winsborough. These samples (23 soil and 42 water) have been processed and analyzed, but the data are not yet available.

DEFINITIONS OF TERMS

Following are definitions of some terms used in this chapter.

Aerophilic (or aerophilous): a preference for non-submerged habitats (such as soil or damp moss) rather than habitats found below the water surface.

Alkaliphilic: a preference for a pH of at least 7.

Benthic: refers to the bottom zone of a water body.

Epipelic: found on the surface of mud, clay, silt or other fine sediments.

Epiphytic: growing on plants or other algae (many diatoms are found attached to algae or submergent aquatic plants).

Halophilic: salt-tolerant.

Oligohalobous: in salt concentrations less than 5500 mg/l (Winsborough 1988:Table 51)

Oligotrophic: a water body with low levels of nutrients (especially nitrogen and phosphorus).

Periphytic: attached to a substrate of some kind.

Planktonic: "growing suspended, floating, or drifting in water" (Wehr and Sheath 2003:845).

Tychoplantktonic: "species that are predominantly planktonic, but capable of prolonged survival on or in sediments" (Wehr and Sheath 2003:848).

RESULTS OF DIATOM STUDIES

Habitat Preference

A minimum of at least 65 distinct species or genera of diatoms was recovered from the bench deposits (Table 7.2). Because some cells could only be identified to generic level (due to poor orientation on the slide, or incompleteness of the diatom), it is possible that a few more species (no more than seven at the most) could be present. About half of the counted diatoms are from preferentially aquatic species (about 47-53

species) and about half (18 species) are species found typically in terrestrial habitats (such as mud, damp moss, or seasonally wet and dry soil; Fig. 7.2).

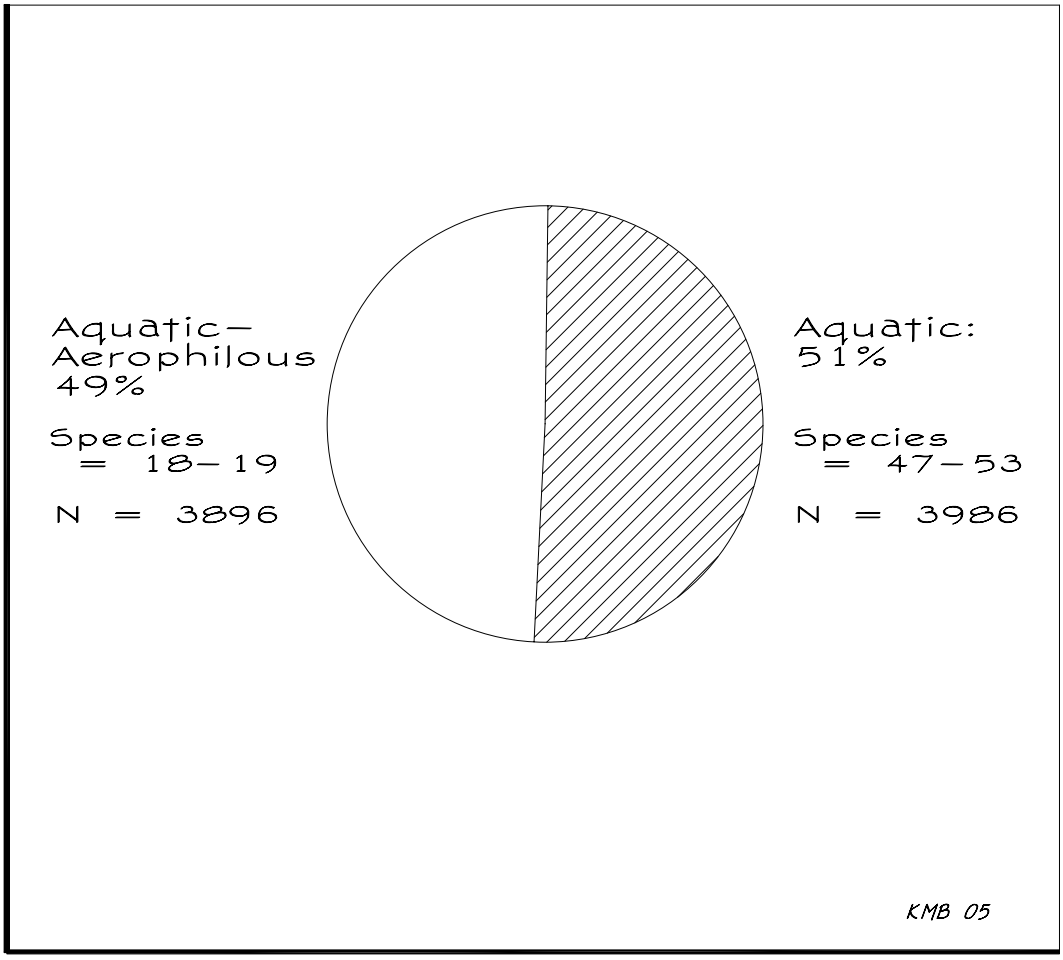

Figure 7.2. Major Habitat Categories for Diatoms From the Bench Deposits. Tallied by cell count, diatoms are about evenly divided between preferentially aquatic species and those found in both aquatic and aerophilous habitats.

The first group represents a diverse mixture of different aquatic species deposited by overbank flooding of Coleto Creek, and perhaps drawn from large sections of the drainage system upbasin. The aquatic assemblage includes three species (*Epithemia turgida*, *Fragilaria ulna*, and *E. adnata*) with abundant cell counts, plus a much larger number of low-frequency species. Many of the aquatic species are represented only by one, two, or three cells.

Table 7.2. Diatom Taxa From the Bench Deposits.

Note: Two additional species (*Opephora martyi* and *Staurosirella pinnata*) are found only in the Lissie terrace.

Achnanthes coarctata
Amphora ovalis
Aulacoseira ambigua
Aulacoseira angustissima
Aulacoseira italica
Caloneis bacillum
Caloneis schumanniana
Cocconeis placentula
Craticula cuspidata
Cyclotella meneghiniana
Cyclotella sp.
Cymatopleura sp.
Cymbella cistula
Cymbella mexicana
Cymbella sp.
Denticula elegans
Denticula cf. *D. kuetzingii*
Diadesmis aerophila
Diadesmis gallica
Diploneis elliptica
Diploneis petersenii
Epithemia adnata
Epithemia argus
Epithemia turgida
Epithemia sp.
Eunotia cf. *E. pectinalis*
Fragilaria capitata
Fragilaria capucina var. *vaucheriae*
Fragilaria elliptica
Fragilaria tenera
Fragilaria ulna
Gomphonema acuminatum
Gomphonema affine
Gomphonema angustum
Gomphonema parvulum
Gomphonema sp.
Hantzschia amphioxys
Luticola goeppertiana
Luticola mutica
Luticola nivalis
Mastogloia smithii
Melosira varians
Meridion circulare var. *constrictum*
Muelleria gibbula
Navicula elginensis
Navicula muticopsis
Navicula oblonga
Navicula placentula
Navicula texana
Neidium affine var. *longiceps*
Neidium sp.
Nitzschia amphibia
Nitzschia cf. *N. frustulum*
Nitzschia palea
Nitzschia tropica
Nitzschia sp.
Pinnularia appendiculata
Pinnularia borealis
Pinnularia braunii
Pinnularia gibba
Pinnularia microstauron
Pinnularia obscura
Pinnularia subcapitata
Pinnularia viridis
Pinnularia sp.
Pseudostaurosira brevistriata
Rhopalodia gibba
Rhopalodia gibberula
Sellaphora pupula
Stauroneis obtusa
Staurosira construens
Surirella sp

The second group represents an assemblage of more adaptable species that can live in aerial habitats. These might have come from saturated mud around seeps, a spring, or a spring run, from off-site temporary floodplain pools, from damp floodplain soil, or from moss growing on the floodplain or on dead wood. This aerophilous assemblage includes the second, third, and fourth most abundant species (*Pinnularia borealis*, *Hantzschia amphioxys*, and *Luticola mutica*) from the bench. Some of these are very common soil diatoms. *Achnanthes*, *Amphora*, *Eunotia*, *Hantzschia*, *Navicula*, *Nitzschia*, and *Pinnularia* have all been reported as soil diatom genera from the Texas coastal plain (King and Ward 1977:Table 2).

Figure 7.3 shows taxa with a total of at least 20 cells in the summed 31 samples (taxa with less than 20 are lumped together in the "other" category). The ten most abundant taxa shown in this diagram are all adapted to seasonal drying of the habitat, regardless of whether it is aquatic or marshy. The following description by Winsborough is based on the initial small group of samples analyzed in February, 1992:

> With the possible exception of *S. ulna*, which is not very useful as an ecological indicator, [the dominant] species are either characteristically soil (*Hantzschia*, *Pinnularia*, and *Navicula*) or shallow water/marsh species (*Epithemia* and *Denticula*). All occur at or above a pH of 7, are indifferent to variable salt concentrations or are stimulated by small amounts of salts. They are littoral, standing water forms, and are found in habitats that contain aquatic vegetation, but that dry out periodically, or become very shallow and marshy. All but one species (*Melosira*) belongs to the category of pennate diatoms, those that are attached to a substrate or crawl actively in or on sediments. The one centric, planktonic diatom (*Melosira*) was probably transported to the site from a deeper water habitat as it forms long chains and would be much more abundant if it was part of the resident population. There is no evidence of a planktonic population, indicating deep (a meter or greater) permanent water (Winsborough 1992a:3-4).

The last statement calls for comment. Geologic evidence (Chapter 4) and freshwater mussels (Chapter 9) suggest the channel of Coleto Creek was fairly deep during accumulation of the bench deposits. The littoral or marsh forms referred to above probably originated in seeps or spring-saturated floodplain sediments at or near the site.

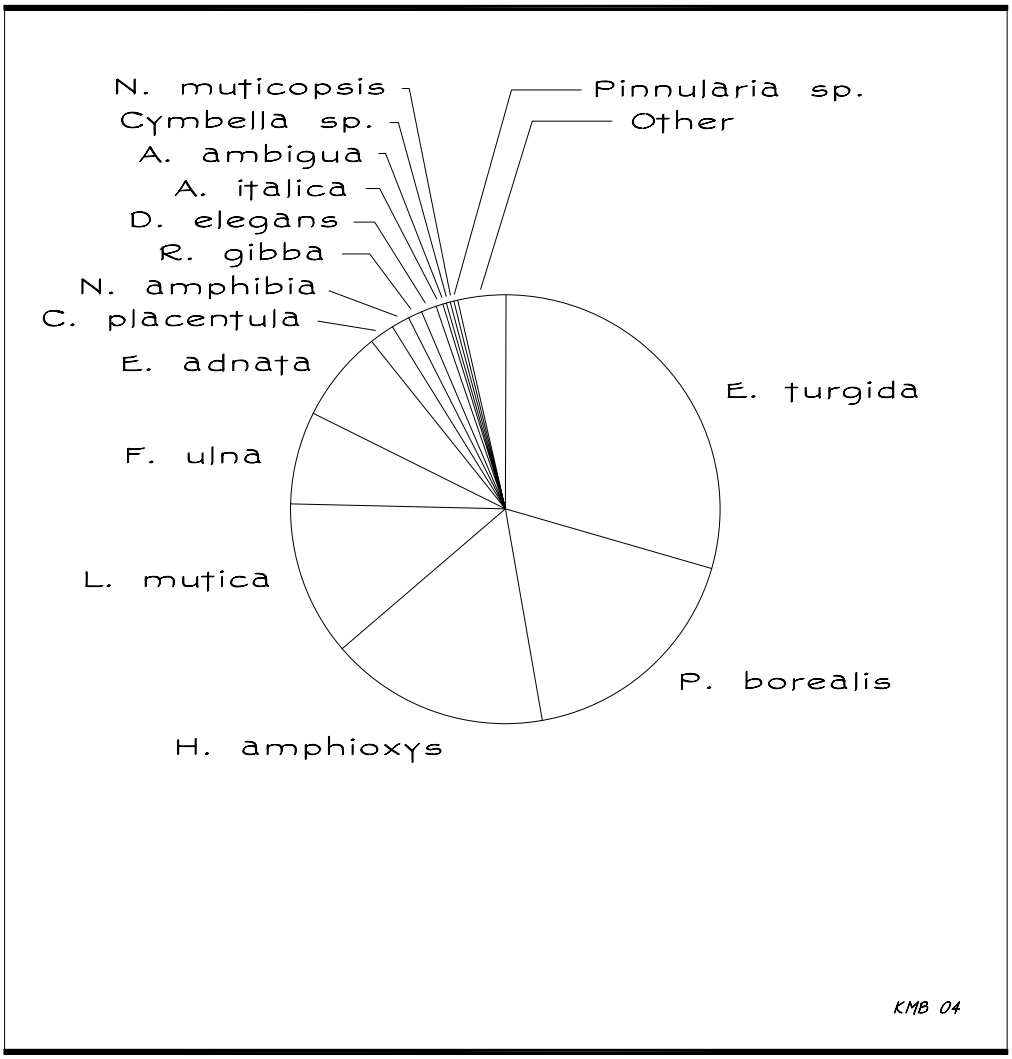

Figure 7.3. Principal Diatom Taxa. This diagram shows all taxa with cell counts of at least 20, ordered by abundance in a clockwise direction beginning with *Epithemia turgida*. Taxa with counts of less than 20 are grouped together in the "other" category.

So many aquatic species, with varying tolerances, are found in the bench deposits that it is difficult to form a general picture of Coleto Creek waters in the Younger Dryas and early Holocene. Certainly, the overwhelming majority of species are epiphytic and alkaliphilous, probably indicating the presence of abundant aquatic vegetation in the creek and pH at least as high as at present (pre-inundation pH was measured at 7.66-8.18; Murray, Jinnette and Moseley 1976:Table 1). Only three species (*Neidium affine* var. *longiceps, Pinnularia appendiculata,* and *P. microstauron*) are particularly acid-tolerant. A few species (*Cyclotella meneghiniana*, *Gomphonema affine*, *Navicula elginensis*, *N. oblonga*, *Nitzschia* cf. *N. frustulum, N. tropica*, *Rhopalodia gibberula*, and *Sellaphora pupula*) tolerate saline water, but they are all rare species with very low cell counts, indicating the water was never significantly brackish. Several species are characteristic of warm waters (*Craticula cuspidata, Denticula elegans, Nitzschia amphibia, Rhopalodia gibberula,* and especially *Fragilaria ulna*). Some of the species (such as *Pinnularia borealis*) in the genus *Pinnularia* might be cool-water indicators.

Patterns of Abundance, Preservation, and Species Diversity

Species richness is simply the number of species in an assemblage or sample; *species diversity* is a mathematical measure that incorporates both the number of taxa and their relative abundances; *evenness* is a mathematical measure of how similar or disparate the abundances are. Both diatom abundance and species richness decline somewhat erratically from the base of the bench deposits toward the top (Fig. 7.4). Diatoms are abundant and diverse in strata 1 and 2A, but decline above 92.20 m (Table 7.3). Abundance and *species richness* are closely correlated (r = 0.84), and as a result *species diversity* and evenness show no major long-term trends.

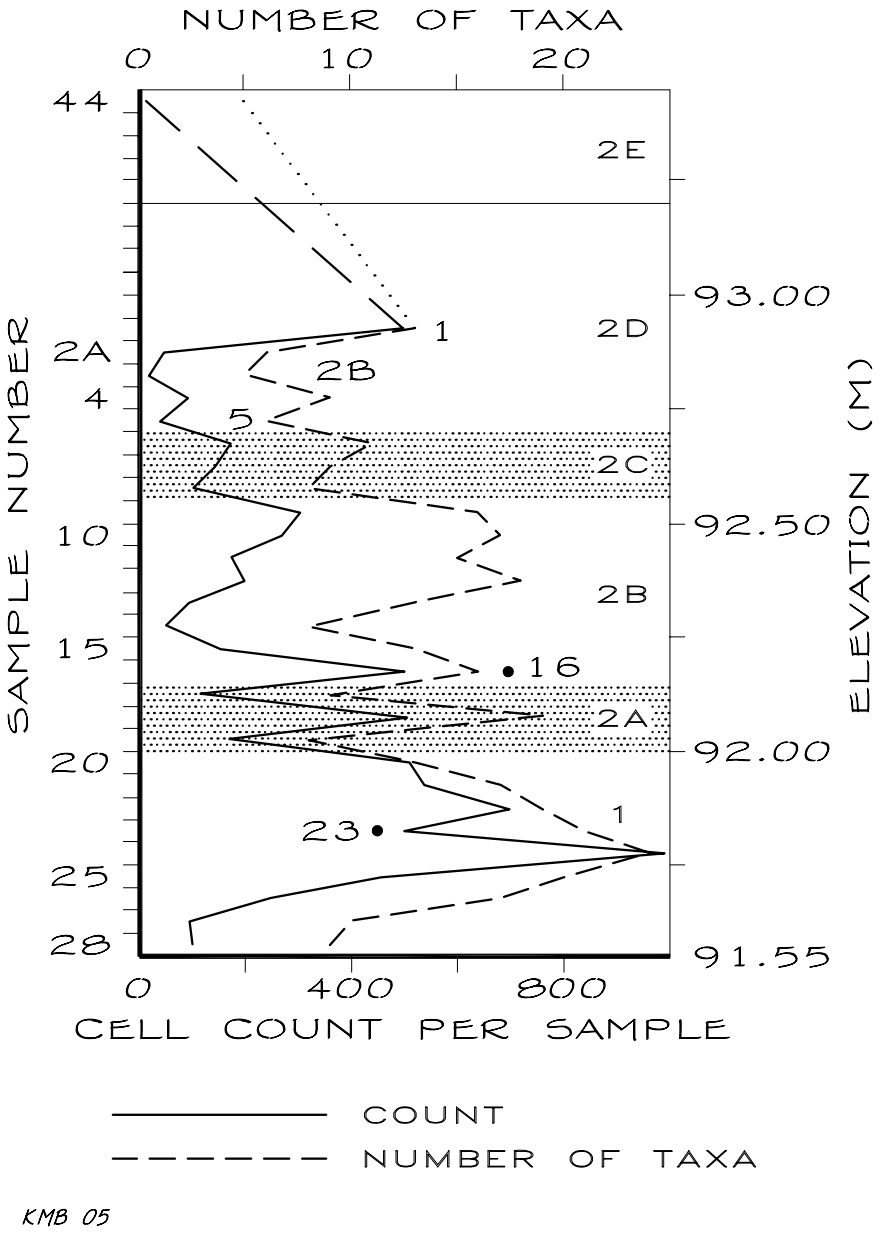

Figure 7.4. Diatom Species Richness and Abundance by Level. Vertical bi-axis plot of the number of taxa and cell count per sample. Samples 2 and 3 are omitted. Two samples (indicated by solid dots) have cell counts of 500. This plot shows that species richness and abundance are heavily correlated, and both diminish upsection and over time, especially above stratum 2A. Compare with Fig. 7.6. Strata are labeled along the right side (note: sample 2B should not be confused with stratum 2B). Diatom abundance and species richness tend to peak in the sandy strata and decline in the muddy strata (shades).

Table 7.3. Diatom Species Richness and Counts by Stratum.

Stratum	Average count per sample	No. of taxa
2E	15	5
2D	47	6.5
2C	159	10
2B	158	16
2A	423	14.2
1	398	16.8

Both of these statistics display only minor fluctuations from bottom to top, except for one major negative excursion at 92.05-92.00 m and a slight trend toward declining diversity above the 92.55-92.50 m level (Fig. 7.5, Table 7.4). There are fewer species in the upper part of the bench deposits, but there are also fewer individuals per species, and because both decline at about the same rate, the diversity index remains relatively constant from bottom to top.

Species diversity is calculated using Simpson's unbiased diversity index, defined as

$$D = 1 - \sum_{i=1}^{s} \left[\frac{n_i(n_j - 1)}{N(N-1)} \right]$$

where D = Simpson's diversity index
n_i = number of cells of species *i* in the sample
N = total cell count in the sample

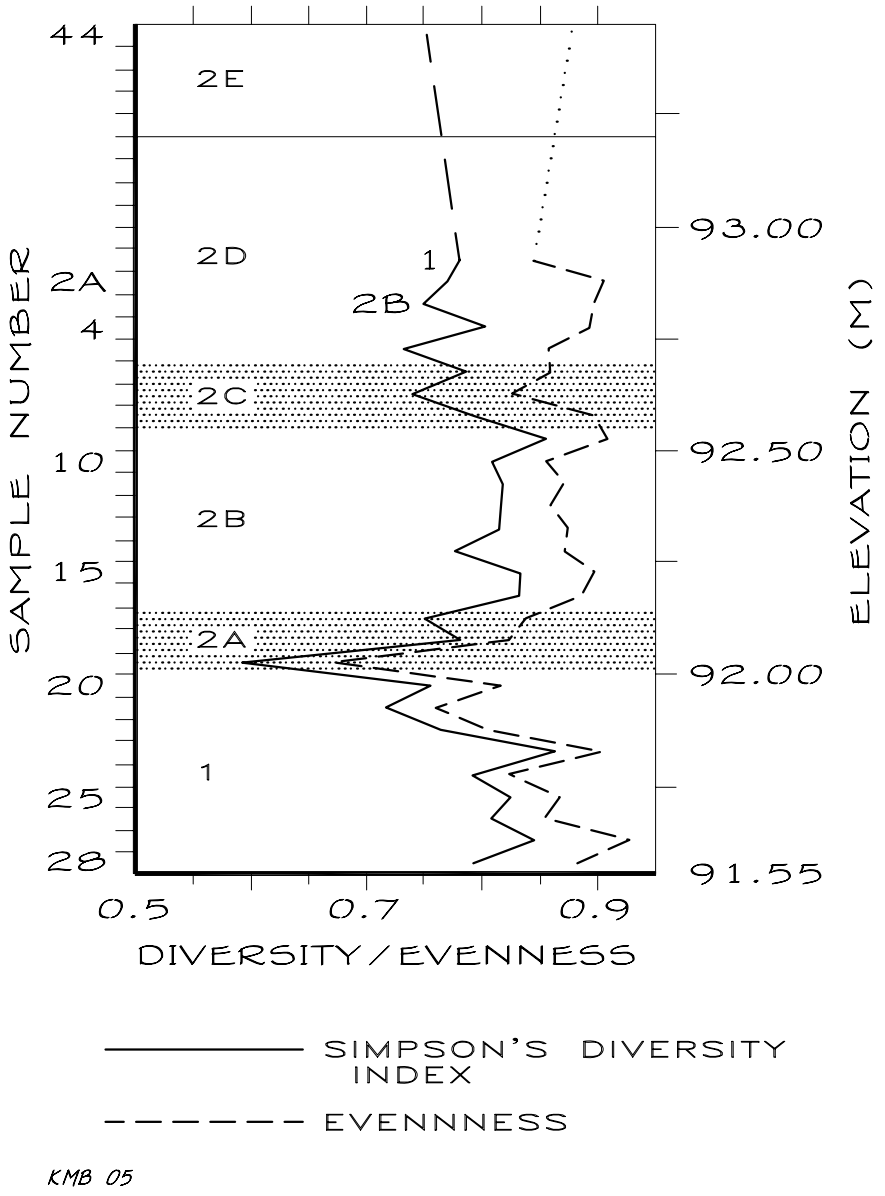

Figure 7.5. Diatom Species Diversity and Evenness by Level. Vertical plot of Simpson's unbiased diversity index and evenness (both indices use the same scale) per sample. Samples 2 and 3 are omitted. Except for one major negative excursion centered at 92.05-92.00 m, both indices show only minor fluctuations from the bottom to the top of the section.

Table 7.4. Diatom Species Diversity.

Sample number	Simpson's diversity index	Evenness	Number of taxa	Cell count
Cutbank, stratum 2E (93.45-93.40 m)				
44	0.752	0.878	5	15
N109 E103				
1	0.781	844	13	500
N110 E102				
2A	0.769	0.905	6	50
2B	0.749	0.896	5	22
4	0.802	0.892	9	93
5	0.732	0.857	6	41
6	0.785	0.859	11	173
7	0.739	0.826	9	144
8	0.792	0.896	8	103
9	0.855	0.909	16	304
10	0.808	0.855	17	269
11	0.817	0.870	15	175
12	0.816	0.859	18	200
13	0.814	0.873	13	93
14	0.776	0.871	8	53
15	0.833	0.896	13	155
16	0.831	0.885	16	500
17	0.750	0.837	9	115
18	0.780	0.822	19	504
19	0.590	0.670	8	172
20	0.754	0.815	13	509
21	0.715	0.759	17	537
22	0.763	0.804	19	700
23	0.862	0.903	21	500
24	0.790	0.823	24	990
25	0.824	0.866	20	456
26	0.807	0.854	17	247
27	0.843	0.927	10	95
28	0.791	0.881	9	100
N109 E103 additional samples				
2	0.767	0.878	7	54
3	0.808	0.940	5	13

The upsection decline in diatom abundance and species richness is presumably due to progressive drying and decline in spring discharge during the Younger Dryas and early Holocene. There is no compelling evidence that it is due to loss of diatoms through dissolution or breakage. Chemical dissolution can remove diatoms from sediments and selectively alter species composition, but this is chiefly seen in saline lake sediments (Ryves *et al*. 2001). Because the bench sediments are mostly quartz sand chemically similar to the diatoms themselves, and because the sediments are buffered by phreatic carbonate, chemical deletion of diatoms is not likely to have been a significant factor, unless the opaline silica in the diatoms is more easily soluble than quartz. The bottom-up decline in abundance and species richness is also the exact opposite of that seen for the snail assemblage, which declines from the top down (see Chapter 8).

The maximum number of species in any one level is 22-24, at the 91.80-91.75 m level in stratum 1 (two categories are identified only to the genus level, so the exact number of species is ambiguous). The minimum number of species is five, at the 92.75-92.70 m level in N109 E102 and the 92.85-92.80 m level in N110 E102 (both from stratum 2D). Much of this upsection decline in species richness (and possibly abundance) is probably due to the loss of aquatic species, because the percentage of aquatic diatoms in any given sample also declines upsection in almost identical fashion (Fig. 7.6).

In comparison to aquatic environments, a diatom assemblage consisting of only 5-24 species per sample is not very diverse. In the Guadalupe River, diatom samples routinely produced about 80-100 species from 1958 to the mid-1970s (Academy of Natural Sciences of Philadelphia 1991:Fig. III-5). A study by Sherwood and Sheath (1999) recorded 66 species for the San Marcos River and 44 species for the Comal River.

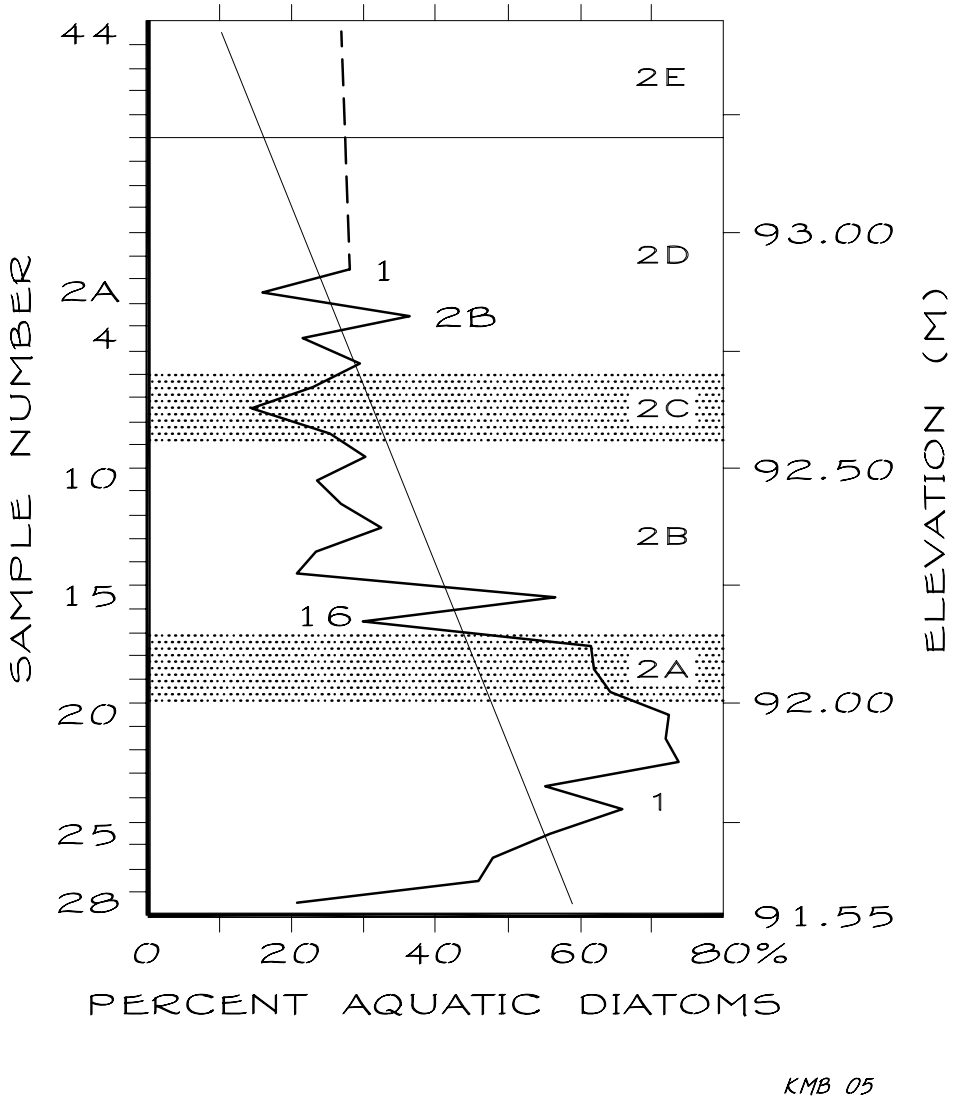

Figure 7.6. Percentage of Aquatic Diatoms by Level. Samples 2 and 3 are omitted. This vertical plot shows a pronounced reduction in the percentage of aquatic diatoms over time, especially above 92.25 m. The fitted trend line has an r^2 value of 0.39. Compare with Fig. 7.4.

Even relatively small creeks may produce over 100 species or subspecies of diatoms (Koch and Risser 1974), though many produce only two or three dozen. Contemporary lakes in stressed environments like the northern Plains may produce

assemblages of about one to three dozen species, while lakes in the eastern US may produce assemblages of over 130 species.

Terrestrial sites produce diatom assemblages of widely varying size. At the upper end of the spectrum are paleontological or archeological sites where pond or cienega deposits have been sampled, like the Gibson site (Marks Beach), where some levels may approach 50 species per sample (Winsborough 1995:Fig. 34). More typical, perhaps, are sites like Wilson-Leonard, where most samples produced very few diatoms at all, and the two most productive samples yielded only 13 and 15 species (Winsborough 1998b:Table 38-2); or the Armstrong site, where individual samples yielded at most three species (Winsborough 2002a:Table 2). Unlike other kinds of proxy data (snails, vertebrates, or pollen) where species richness in any one sample may be inflated by time-averaging, diatom samples from archeological or paleontological sites often seem to produce species lists that are rather limited in comparison to contemporary sampling. In part, this is because archeological or paleontological samples are less spatially extensive, and in part because the diatom samples are diluted by sediment.

Stratigraphic Distribution of Species

A few species of diatoms (*Cocconeis placentula, Rhopalodia gibba*, and *Pinnularia borealis*) not only occur in abundance, but are also widely distributed from the bottom to the top of the bench section (Table 7.5) or increase slightly in abundance toward the top (*Hantzschia amphioxys, Luticola mutica*). Aside from their abundance, these persistent species are distinguished by being widespread, common, and relatively well-documented in the diatom literature. In general, they are cosmopolitan and include both aquatic and aerophilic/aquatic forms. A few examples are shown in Fig. 7.7.

Another group (Figs. 7.8, 7.9) consists of species that are concentrated in the lower part but drop out toward the top of the section (for example, *Achnanthes coarctata*, *Aulacoseira italica*, *A. ambigua*, *Cymbella mexicana*, *Epithemia adnata*, *Eunotia* cf. *E. pectinalis*, *Fragilaria capitata*, *F. capucina* var. *vaucheriae*, *Navicula muticopsis*, and *Pinnularia appendiculata*). Except for *N. muticopsis* and *P. appendiculata*, these are mostly aquatic species occurring in low to moderate abundance. It is notable that *Epithemia adnata*, which does not tolerate dry conditions as well as *Epithemia turgida* (Winsborough, personal communication 2005), drops out toward the top of the section while *E. turgida* persists, even into stratum 2E, though becoming less frequent. Some of these species might have been more stratigraphically persistent if their sample sizes had been larger. *Nitzschia amphibia* seems to appear uniquely in sandy units (Fig. 7.7).

A third group (Fig. 7.10) consists of a few rare species found in very low numbers only in the upper half or near the top of the section (*Epithemia argus*, *Fragilaria elliptica, Gomphonema affine, G. angustum, Meridion circulare* var. *constrictum, Nitzschia tropica, Pinnularia braunii, P. subcapitata,* and *Surirella* sp.). These are nearly all aquatic (including a couple of salt-tolerant species) and are often represented by only one or two cells. Their restricted stratigraphic range may be largely due to small sample size.

The remaining species (Fig. 7.11 shows a few examples) are scattered irregularly through the stratigraphic section. These (for example, *Denticula elegans*, *Mastogloia smithii*, *Pinnularia viridis*, and *Stauroneis obtusa*) generally have rather low cell counts and show no distinguishing stratigraphic patterns.

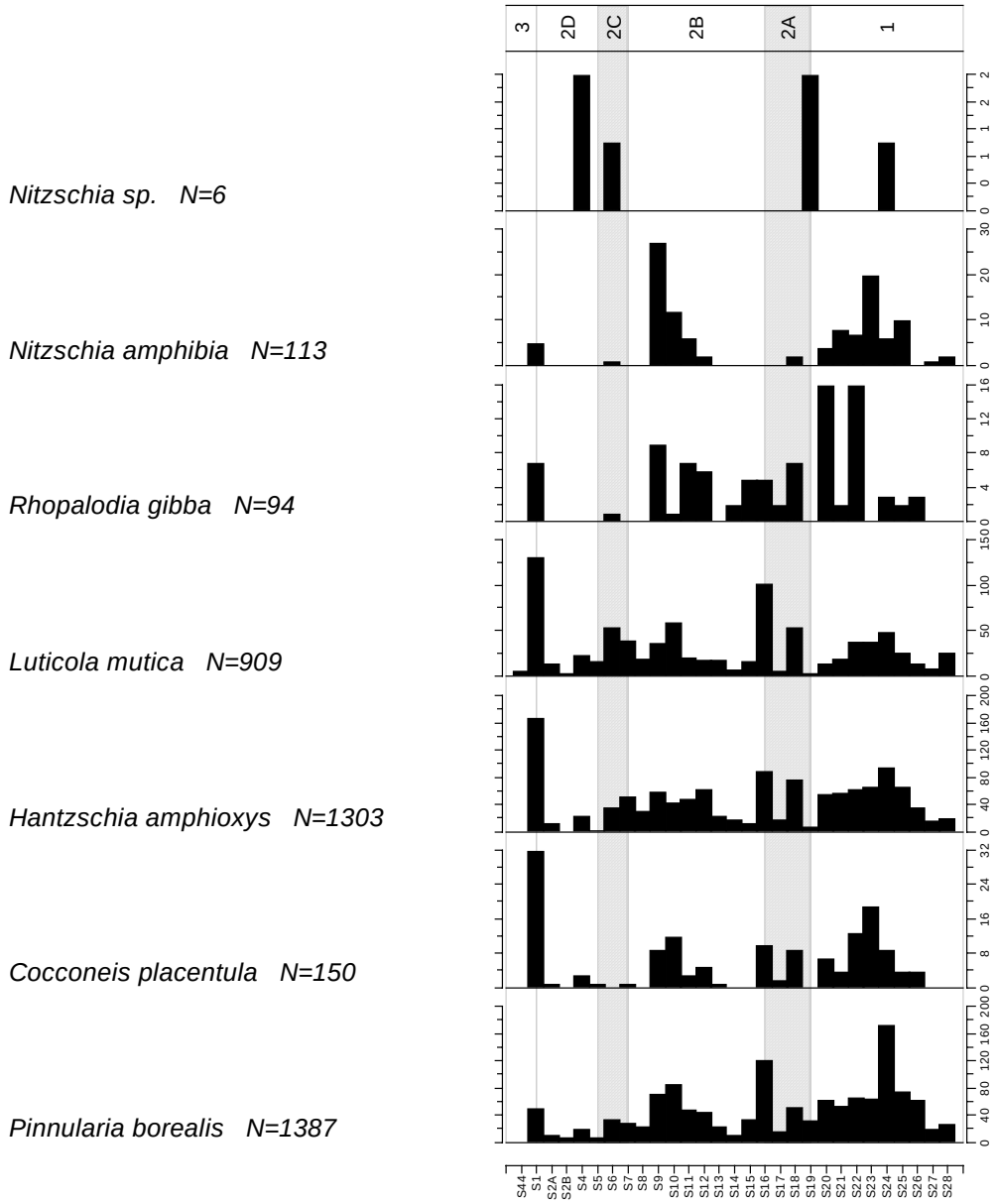

Figure 7.7 (*landscape view*). Persistent Diatom Species. Selected examples of species persisting or recurring throughout the stratigraphic section. In this and following figures, the X axis (when viewed in landscape mode) consists of cell counts; width is constant but scaling is variable by species. Cell counts for the entire column are given next to the species name. This scaling style emphasizes vertical patterns within a species and de-emphasizes relative proportions of species. Lower counts in the muddy units (shaded) may have resulted from turbidity restricting photosynthesis (for aquatic species).

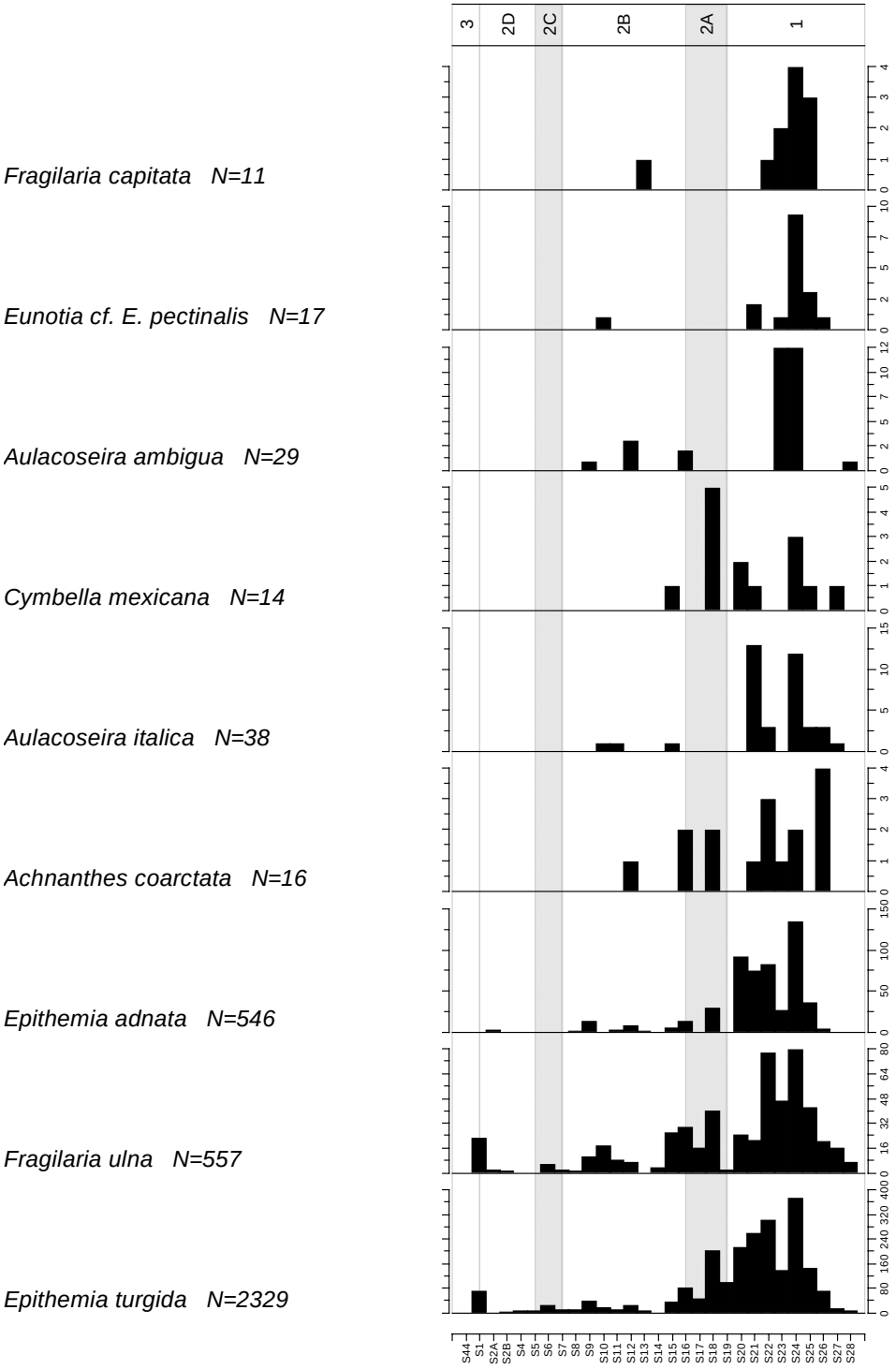

Figure 7.8 (*landscape view*). Decreasing Diatom Species.

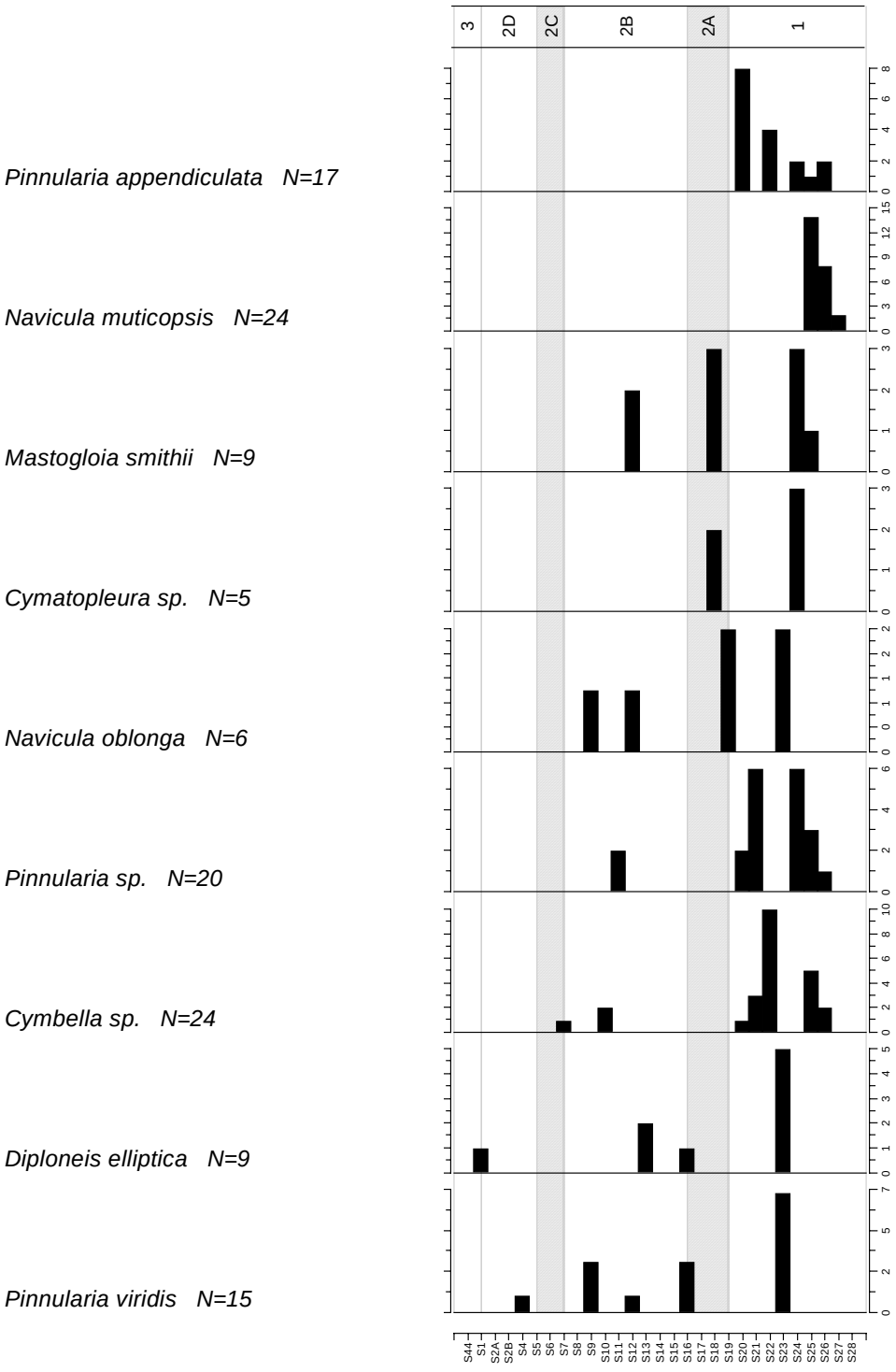

Figure 7.9 (*landscape view*). Additional Decreasing Diatom Species.

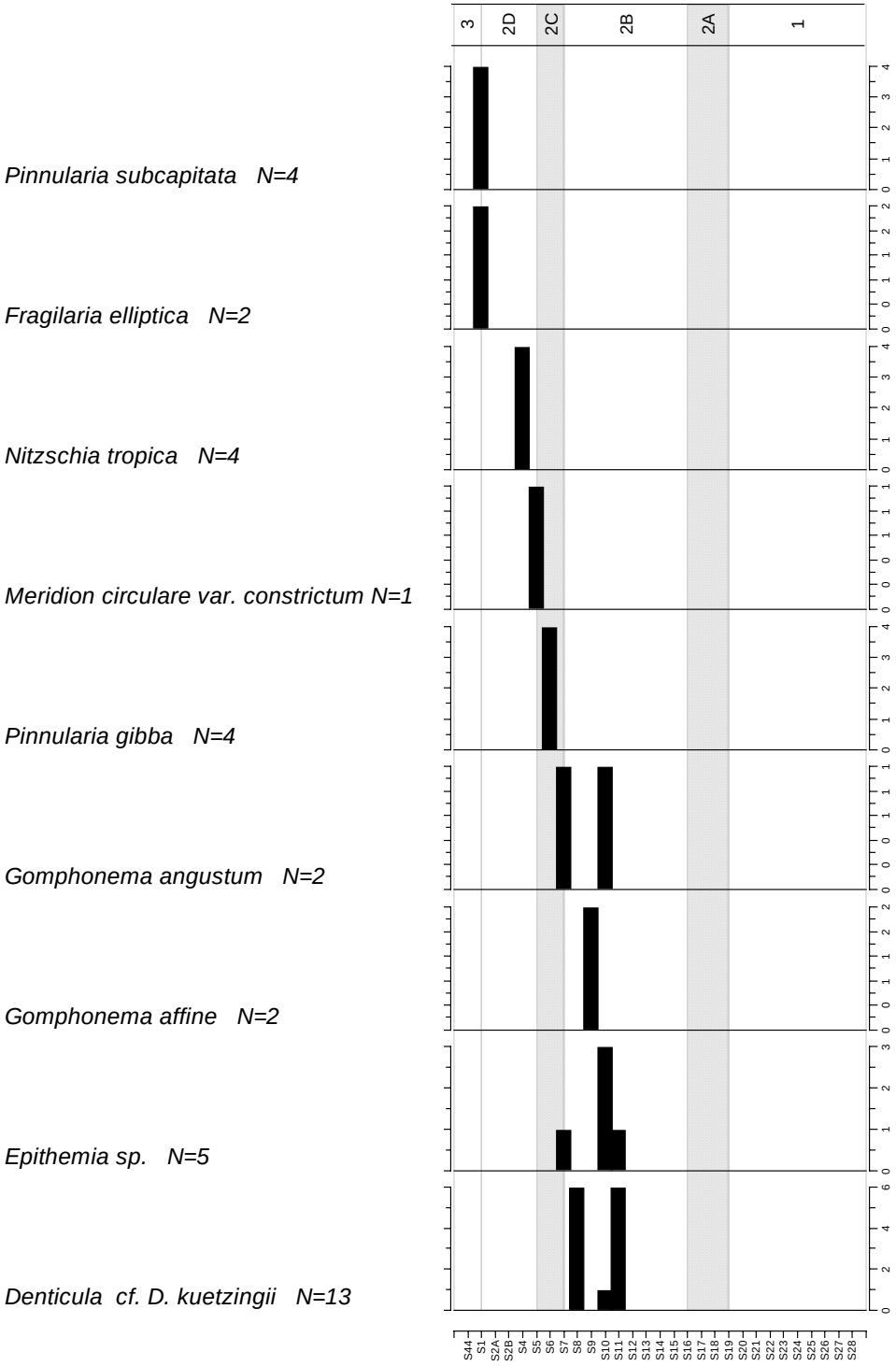

Figure 7.10 (*landscape view*). "Increasing" or Late-Appearing Diatom Species.

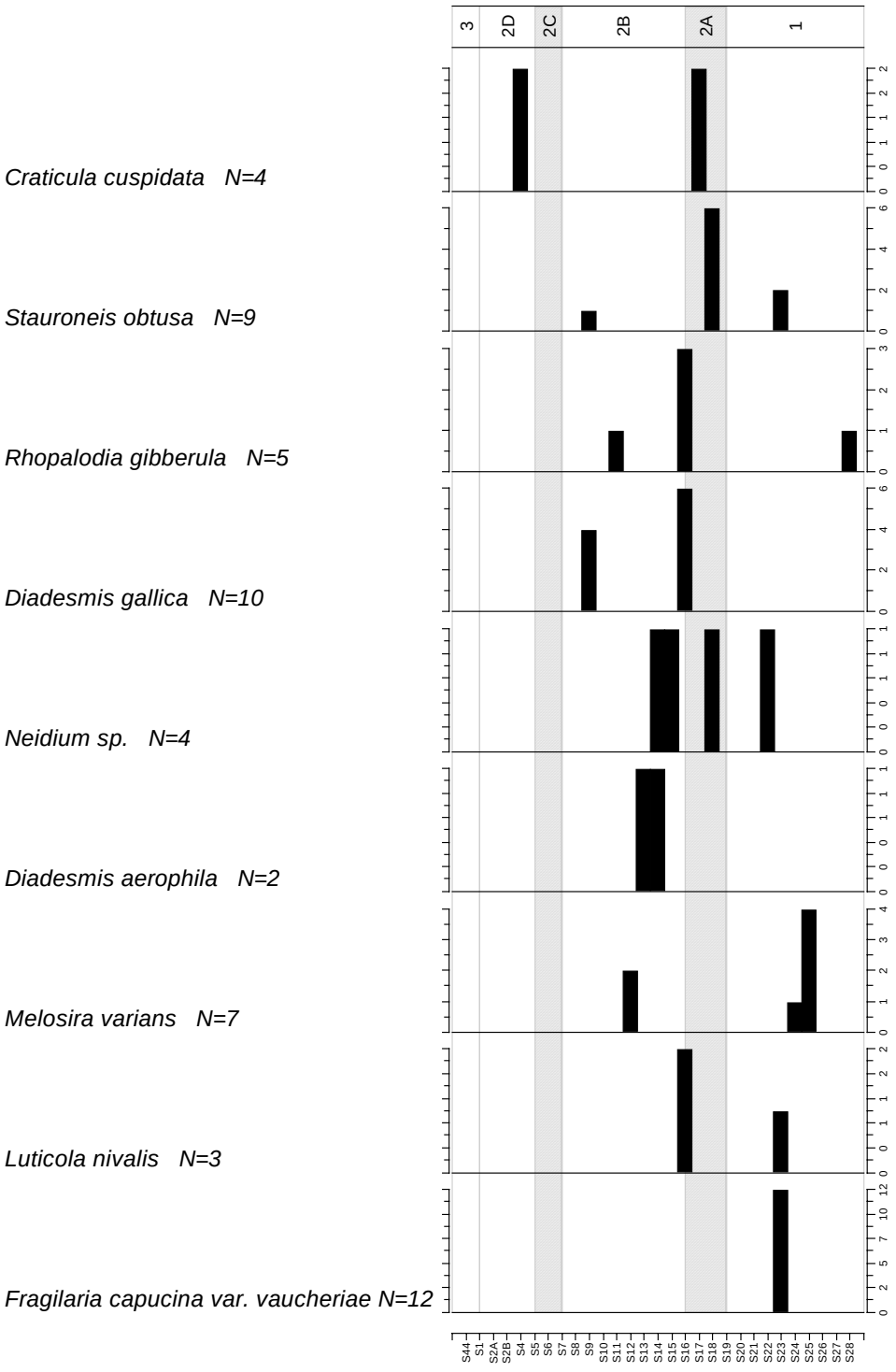

Figure 7.11 (*landscape view*). Unpatterned Diatom Species.

Table 7.5. Diatom Species Counts by Sample (Bench Deposits).

Sample number	*Achnanthes coarctata*	*Amphora ovalis*	*Aulacoseira ambigua*	*Aulacoseira angustissima*	*Aulacoseira italica*	*Caloneis bacillum*	*Caloneis schumanniana*	*Cocconeis placentula*	*Craticula cuspidata*	*Cyclotella meneghiniana*	*Cyclotella sp.*	*Cymatopleura sp.*	*Cymbella cistula*	*Cymbella mexicana*	*Cymbella sp.*	*Denticula elegans*	*Denticula cf. D. kuetzingii*	*Diadesmis aerophila*	*Diadesmis gallica*	*Diploneis elliptica*	*Diploneis petersenii*
44																					
1								32					1							1	
2																					
3								1								2					
2A								1													
2B																					
4								3	2												
5								1													
6																3					
7								1							1						
8																	6				
9			1					9								7			4		
10		1			1			12							2		1				
11					1			3									6				
12	1		3				1	5		1						2					
13						2		1										1		2	2
14																		1			
15					1									1							
16	2	2						10								22			6	1	
17								2	2												
18	2							9			1	2		5		1					
19																15					
20								7						2	1						
21	1				13			4					1	1	3						
22	3			3	3			13							10						1
23	1		12					19								22				5	
24	2		12		12			9				3		3							
25					3			4						1	5						
26	4				3			4							2						
27					1									1							
28			1																		
Sum	16	3	29	3	38	2	1	150	4	1	1	5	2	14	24	74	13	2	10	9	3

(Table 7.5, continued from previous page)

Sample number	*Epithemia adnata*	*Epithemia argus*	*Epithemia turgida*	*Epithemia sp.*	*Eunotia cf. E. pectinalis*	*Fragilaria capitata*	*Fragilaria capucina v. vaucheriae*	*Fragilaria elliptica*	*Fragilaria tenera*	*Fragilaria ulna*	*Gomphonema acuminatum*	*Gomphonema affine*	*Gomphonema angustum*	*Gomphonema parvulum*	*Gomphonema sp.*	*Hantzschia amphioxys*	*Luticola goeppertiana*	*Luticola mutica*	*Luticola nivalis*	*Mastogloia smithii*
44			3							1						2		7		
1			73					2		23						168		132		
2			12							4						4		12		
3			2							3										
2A	4									3						15		14		
2B			6							2						1		4		
4			11													24		24		
5			10													3		17		
6	1		27							6						38		55		
7			14	1						3			1			53		40		
8	2	2	14							2						32		20		
9	14		44							11		2				61		37		
10	1		22	3	1					18			1			45		60		
11	4		13	1						9						49		21		
12	9		27							8						64		19		2
13	3		12			1				1						24		19		
14			4							4						20		8		
15	6		40							27						15		17		
16	14		85							30						91		102	2	
17	1		49							17						19		6		
18	31		204							41						78		54		3
19			104							3						9		4		
20	93		217							25						57		14		
21	75		263		2					22						59		20		
22	83		305			1				78	1					64	1	39		
23	28		142		1	2	12			47						67		39	1	
24	135		374		9	4				80				4		95	2	49		3
25	37		149		3	3				43						68		27		1
26	5		76		1				1	21					1	38		14		
27			17							17						18		9		
28			10							8						22		26		
Sum	546	2	2329	5	17	11	12	2	1	557	1	2	2	4	1	1303	3	909	3	9

(Table 7.5, continued from previous page)

Sample number	*Melosira varians*	*Meridion circulare v. constrictum*	*Muelleria gibbula*	*Navicula elginensis*	*Navicula muticopsis*	*Navicula oblonga*	*Navicula placentula*	*Navicula texana*	*Neidium affine* var. *longiceps*	*Neidium sp.*	*Nitzschia amphibia*	*Nitzschia cf. N. frustulum*	*Nitzschia palea*	*Nitzschia tropica*	*Nitzschia sp.*	*Pinnularia appendiculata*	*Pinnularia borealis*	*Pinnularia braunii*	*Pinnularia gibba*	*Pinnularia microstauron*	*Pinnularia obscura*
44																	2				
1											5						51				
2												1					20	1			
3																	5				
2A																	13				
2B																	9				
4														4	2		22				
5		1															9				
6											1				1		36		4		
7																	30				
8																	25				
9						1					27						73				
10											12						86				2
11											6						50				
12	2					1					2						46				
13																	24				1
14										1							13				
15									3	1		2	2				35				
16																	122				
17																	17				
18								3		1	2						53				
19						2									2		33				
20											4					8	63				
21											8						55			2	
22										1	7					4	67				
23				2		2					20						65				
24	1						1				6				1	2	174				
25	4		2		14						10					1	76				
26					8											2	63				
27					2						1						21				
28				1							2						29				
Sum	7	1	2	3	24	6	1	3	3	4	113	3	2	4	6	17	1387	1	4	2	3

(Table 7.5, continued from previous page)

Sample number	*Pinnularia subcapitata*	*Pinnularia viridis*	*Pinnularia sp.*	*Pseudostaurosira brevistriata*	*Rhopalodia gibba*	*Rhopalodia gibberula*	*Sellaphora pupula*	*Staurosira construens*	*Staurosira construens*	*Surirella sp.*	Row totals
44											15
1	4				7					1	500
2											54
3											13
2A											50
2B											22
4		1									93
5											41
6					1						173
7											144
8											103
9		3			9			1			304
10					1						269
11			2		7	1	2				175
12		1			6						200
13											93
14					2						53
15					5						155
16		3			5	3					500
17					2						115
18					7			6	1		504
19											172
20			2		16						509
21			6		2						537
22					16						700
23		7		4				2			500
24			6		3						990
25			3		2						456
26			1		3						247
27				8							95
28						1					100
Sum	4	15	20	12	94	5	2	9	1	1	7882

Aquatic Diatoms and Suspended Load Content

Most research on diatom autecology has focused on chemical variables like pH, salinity, conductivity, and the like. For Coleto Creek during the Younger Dryas and early Holocene, these factors were probably less variable than in the lakes that are often the focus of diatom studies. In the present context, fluvial variables like suspended load content, water depth, velocity and turbulence, and water temperature are probably much more relevant, but these are less often studied by diatom specialists, making it more difficult to discern relationships between the diatom assemblage and the geology of the bench deposits.

One exception to this emphasis is a study done in 1996-99 by Blinn and Herbst (2003) of substrates in 38 stream habitats in the Lahontan Basin. The study showed that dissolved oxygen, alkalinity, conductivity, and substratum were all correlated with diatom community structure. The study is particularly useful because a few species found at Berger Bluff are included. *Aulacoseira italica* was found in habitats with high gradients, high discharge, coarse substrate, high canopy cover, and low conductance. *Cyclotella meneghiniana*, *Nitzschia frustulum*, *N. palea*, and *Rhopalodia gibba* were found in habitats with low gradients, low discharge, fine substrate, low canopy cover, and high conductance (Blinn and Herbst 2003:3). They also found that

> Species of *Hantzschia*, *Navicula*, *Nitzschia*, and *Surirella* were most abundant in low elevation assemblages, with fine substrata, reduced canopy, low gradients, low discharges, and high conductance and lowest in habitats with high ecological integrity. Also, based on indices of % fines and sand and % embeddedness, species such as *Cocconeis placentula* var. *euglypta*, *Cyclotella meneghiniana*, *Fragilaria ulna*… *Nitzschia frustulum*, *Nitzschia palea*… and *Rhopalodia gibba* were considered to be most tolerant of disturbed sites with substrata composed of a high percentage of fines and sand…. (Blinn and Herbst 2003:3).

The authors define an index (FSI) of % fines and sand which can be used as an indicator of the siltation tolerance of each diatom species. See Blinn and Herbst (2003:6) for a definition of the index. Species in their study ranged from a minimum index of 28 to a maximum of 82 (representing the most silt-tolerant). Species that are also found at Berger Bluff are shown in Table 7.6, ranked in order from most tolerant to least tolerant.

Table 7.6. Siltation Tolerance of Selected Diatom Species from the Bench Deposits.

Species	Index	Count
Nitzschia amphibia	78	113
Hantzschia amphioxys	73	1303
Meridion circulare	73	1
Sellaphora pupula	71	2
Amphora ovalis	70	3
Gomphonema parvulum	69	4
Luticola mutica	68	909
Aulacoseira italica	65	38
Gomphonema angustum	59	2
Pinnularia subcapitata	50	4

Source: Blinn and Herbst (2003:Table 6)

From the rankings, it is apparent that all the species are fairly silt-tolerant, but *Nitzschia amphibia* is most tolerant. Only *H. amphioxys*, *L. mutic*a, and *N. amphibia* occur in any abundance in the bench deposits. Of the species listed in the table above, two of the most abundant species (*H. amphioxys* and *L. mutica*) are stratigraphically persistent species that become progressively somewhat more abundant through time. Most of the remaining species (except for *M. circulare* and *P. subcapitata*) are found in the lower two-thirds or lower part of the stratigraphic section. *Nitzschia amphibia* appears early in the sequence and then again in the upper part of stratum 2B.

Correspondence Analysis of the Diatom Data

Correspondence analysis is an exploratory technique for analyzing two-way contingency tables. Here the *variable*s are counts of diatom species and the *case*s are the samples drawn in most cases from 5 cm excavation levels. The analysis extracts *axes*, or gradients of variation, that are orthogonal and independent of each other.

The unmodified provenience table of diatom counts (Table 7.5) is inherently somewhat unsuitable for ordination studies. Good practice in multivariate analysis requires that there be at least as many samples as variables, but the unmodified table has 72 variables (taxonomic categories) by 31 cases (samples). As an experiment, a correspondence analysis was done using the unmodified data table, but it was clear that better results would be obtained by deleting as many of the least informative taxonomic categories as possible. A wide variety of modifications was tried (including log and percentage transformations of the counts), but ultimately the most interpretable results were obtained by

- Entirely deleting four cosmopolitan species that are ecologically undiagnostic (*Fragilaria ulna*, *Cocconeis placentula*, *Nitzschia amphibia*, and *Denticula elegans*)
- Deleting all taxa identified only to generic level, except for *Cymatopleura* sp.

Cymatopleura was exempted because there are no species in this genus identified in the deposits, so the taxon is unique as it stands.

Deletion of these taxa reduced the data table to 60 variables by 31 cases, and as a result, about 61% of the variance (or "inertia," as it is sometimes termed in correspondence analysis) was accounted for by the first three axes extracted, compared to only 37% for the unmodified table. The table is still twice as variable-heavy as it should be, but it yielded interpretable results, so the analysis is presented here. The final and best solution also featured downweighting of rare species and detrending of scores. The correspondence analysis was done using MVSP 3.1. The first axis accounts for 50% of the variance (inertia). Positive loadings represent diatoms characteristic of wet conditions or flooding, and all are benthic, epiphytic or epilithic hardwater taxa (except possibly *A. italica*, both planktonic and benthic; Barbara Winsborough, personal communication). Negative loadings are opportunistic benthic species from dry or temporarily wet habitats. This axis seems to represent a gradient of continuity in groundwater or floodwater saturation. The second axis accounts for only 6% and is not readily interpretable. It seems to feature mostly rare aquatic species. Negative loadings include several characteristic of water with moderate to high electrolyte content. Some of the highest loadings (selected from the total 60 variables) are listed below:

Axis 1 (50%): Continuity of groundwater/floodwater saturation

	Loading	Sample Size	Habitat
Axis 1 positive loadings			
Pinnularia appendiculata	2.317	17	aquatic
Epithemia adnata	2.145	546	aquatic
Aulacoseira italica	2.170	38	aquatic
Cymbella mexicana	1.882	14	aquatic
Eunotia cf. *E. pectinalis*	1.749	17	aquatic
Fragilaria capitata	1.704	11	aquatic
Epithemia turgida	1.690	2329	aquatic
Luticola goeppertiana	1.680	3	aerophilous/ aquatic
Cymatopleura sp.	1.509	5	aquatic
Pinnularia microstauron	1.467	2	aquatic
Axis 1 negative loadings			
Gomphonema angustum	-1.205	2	aquatic
Denticula cf. *D. kuetzingii*	-1.038	13	aquatic
Luticola mutica	-0.818	909	aerophilous/ aquatic
Diadesmis aerophila	-0.803	2	aerophilous
Rhopalodia gibberula	-0.786	5	aquatic, salt-tolerant
Pinnularia obscura	-0.688	3	aerophilous/aquatic
Amphora ovalis	-0.416	3	aquatic
Diadesmis gallica	-0.158	10	aerophilous

Axis 2 (6 %): Unidentified

	Loading	Sample Size	Habitat
Axis 2 positive loadings			
Pinnularia braunii	9.482	1	aquatic
M. circulare v. *constrictum*	6.938	1	aquatic
Pinnularia obscura	5.984	3	aerophilous/aquatic
Nitzschia cf. *N. frustulum*	5.535	3	aquatic, widespread
Gomphonema angustum	4.460	2	aquatic
Navicula oblonga	4.375	6	aquatic, salt-tolerant
Amphora ovalis	4.264	3	aquatic
Navicula muticopsis	2.802	24	aerophilous/aquatic
Aulacoseira italica	2.768	38	aquatic
Eunotia cf. *E. pectinalis*	2.390	17	aquatic
Fragilaria tenera	2.187	1	aquatic

Axis 2 negative loadings

Denticula cf. *D. kuetzingii*	-2.598	13	aquatic
Rhopalodia gibba	-2.093	94	aquatic
Diadesmis aerophila	-1.951	2	aerophilous
Pinnularia appendiculata	-1.582	17	aquatic
Caloneis schumanniana	-1.530	1	aquatic
Sellaphora pupula	-1.476	2	aquatic, salt-tolerant

Table 7.7 lists the case scores for the 31 diatom samples from the bench deposits for the first two axes. Figure 7.12 shows a plot of these scores on the first two axes. In the figure, each data point is identified both by the sample number (as listed in Table 7.1) and by its stratum (strata are hyphenated for samples at contacts between strata). Solid and dashed lines outline clusters of samples from muddy and sandy strata. This plot demonstrates that each stratum has a fairly distinct diatom assemblage signature. There is some overlap (especially between strata 1 and 2A). There are a few outliers (samples 1, 9, 10, 28), and of course the single sample from stratum 2E sits as an outlier at the left edge of the plot, but otherwise the samples cluster well. In Figure 7.12, the horizontal axis appears to represent an aquatic gradient from more drought-prone conditions on the left side to more persistently saturated or flooded conditions on the right. The various strata are arrayed very roughly in sequence from right to left on the plot, indicating that in general there is an increasing emphasis on species that can withstand periodic desiccation, moving upward in the stratigraphic sequence. Stratum 2D is distinguished by a greater response to Axis 2.

Table 7.7 lists the case loadings for each of the 31 samples; only the first two axes extracted are shown. In Figure 7.13, these scores (except for samples 2 and 3) are plotted stratigraphically.

Table 7.7. Correspondence Analysis of Diatom Samples: Case Scores.

	Axis 1	Axis 2
Eigenvalues	0.218	0.026
Percentage	50.09	6.07
Cumulative Percentage	50.09	56.15
	Case (sample) scores	
Cases (samples)	Axis 1	Axis 2
44 (cutbank)	0.003	0.365
1	0.088	0.019
2A	0.034	0.230
2B	0.521	0.774
4	0.113	0.334
5	0.176	0.562
6	0.115	0.325
7	0.000	0.197
8	0.189	0.137
9	0.462	0.251
10	0.121	0.597
11	0.254	0.162
12	0.452	0.081
13	0.271	0.308
14	0.132	0.070
15	0.741	0.402
16	0.333	0.373
17	0.925	0.240
18	0.933	0.115
19	1.233	0.519
20	1.305	0.000
21	1.310	0.195
22	1.231	0.100
23	0.848	0.217
24	1.169	0.269
25	0.969	0.294
26	0.828	0.474
27	0.522	0.486
28	0.086	0.447
Additional samples (N109 E103)		
2	0.392	0.790
3	0.770	1.105

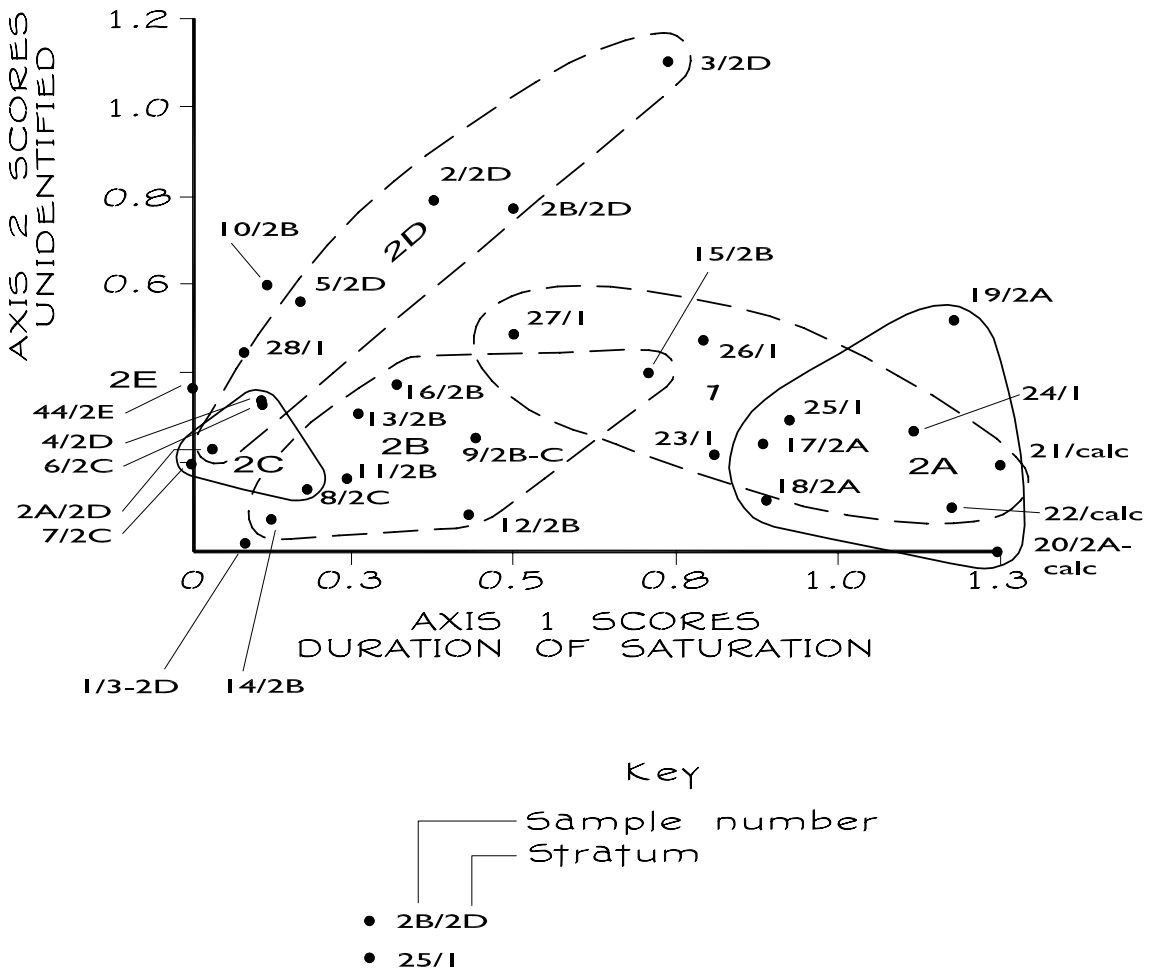

Figure 7.12. Correspondence Analysis of Diatom Samples from the Bench Deposits. Bi-axis plot showing scores on the first two axes. Each point represents a single diatom sample. Solid lines outline clusters of samples from muddy strata; dashed lines outline clusters from sandy strata. A single sample from stratum 2E lies at the left edge. Note that the strata cluster fairly well, showing only partial overlap. Samples toward the right side of the plot have diatom assemblages emphasizing species usually found in permanent water; samples toward the left have species adapted to periodic desiccation. The gradient represented by axis 2 is unidentified, but may have something to do with electrolyte tolerance. Only stratum 2D seems to score very high on this axis. Hyphenated labels designate samples from contacts between strata (for example, "2A-calc" is from the contact area between stratum 2A and the underlying calcrete zone). Also note that samples 2A and 2B should not be confused with strata 2A and 2B.

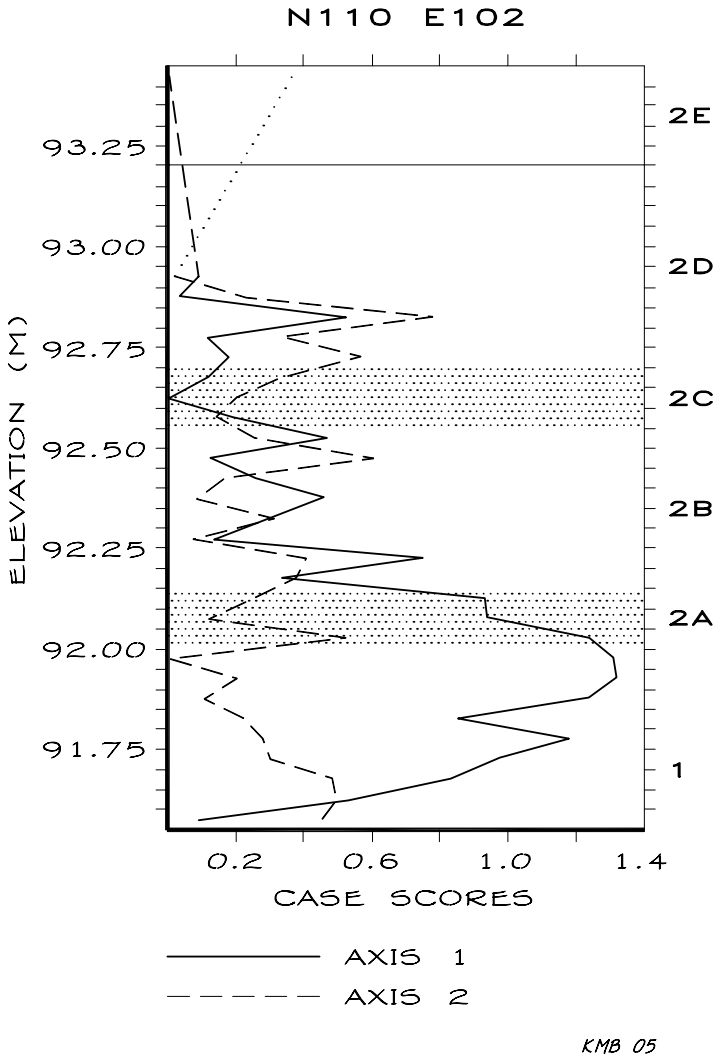

Figure 7.13. Vertical Plot of First Two Axes, Correspondence Analysis of Diatom Samples. Case scores from analysis of simplified matrix are shown; samples 2 and 3 are used in the analysis, but omitted from this plot. Note the similarity of this plot to figures 7.4 and 7.6.

Axis 1 has high scores at the top of stratum 1, in the calcrete zone, diminishing rapidly through stratum 2A and into stratum 2B, and reaching a minimum in strata 2B and 2E. In fact the vertical pattern of axis 1 (Fig. 7.8) is almost identical to the plot of aquatic diatoms shown in Fig. 7.6, a clear indication that both are essentially measuring the same thing – the abundance of diatoms preferring consistently flooded or water-saturated conditions. It is apparent that this assemblage experiences a step reduction in abundance at the top of stratum 1 and continues to diminish as sediment accumulates on the floodplain.

SPECIES ACCOUNTS: DIATOMS FROM THE BENCH DEPOSITS

The following brief species accounts (modified from those provided by Barbara Winsborough) pertain to taxa from the bench deposits. Autecological descriptions without literature citations are based on the personal experience of the analyst, Barbara Winsborough. Two species unique to the Lissie terrace (*Opephora martyi* and *Staurosirella pinnata*) are described separately at the end of this list. Digital photographs of biosilica were taken with the TARL videomicroscopy system. All photos (except two at 10X as noted) were taken through a 50X planchromatic objective lens; diatoms were identified by Barbara Winsborough from printouts. For comparison with water chemistry optima listed in the accounts, the following USGS data for Coleto Creek covering several recent years are listed.

Table 7.8. Contemporary Water Chemistry of Coleto Creek.

pH	7.18 ± 0.34	(range, 6.6-8.0)
Bicarbonate (mg/l)	181.12 ± 47.15	(range, 73.0-280.0)
Hardness (mg/l, as $CaCO_3$)	175.61 ± 53.13	(range, 57.0-250.0)
Calcium (mg/l)	58.28 ± 28	(range, 20.0-86.0)
Sodium (mg/l)	51.19 ± 27.06	(range, 4.4-103.0)

Source: USGS water quality data for station 08177000, Coleto Creek at Schroeder

Period of record: April 4, 1962 to February 24, 1970

Achnanthes coarctata (Brébisson) Grunow (Fig. 7.8)
N = 16

Both aerophile and aquatic; commonly associated with mosses and lichens (Kingston 2003:623). Found in soil, on rocks, and in streams. In damp, shaded subaerial habitats in Iowa (Stoermer 1962:89); in moss and lichens (Dodd and Stoermer 1962:Table 1). Reported from sandstone cliff walls in Ohio (Casamatta *et al*. 2002:Table2). As a group, the genus prefers cooler water temperatures (Vinson and Rushforth 1989:52).

Amphora ovalis (Kützing) Kützing
N = 3

Aquatic, in freshwater lakes and streams; epiphytic and alkaliphilic. Epiphytic on *Phragmites* stems (Müller 1999:Table 1). A minor species in the Guadalupe River, most abundant in September and November (Academy of Natural Sciences of Philadelphia 1991:VII-12). Optimum pH is 8.13 in German lakes and rivers (Schönfelder *et al*. 2002); 8.0-8.6 in East Africa (Gasse and Tekaia 1983:Table 6). Occurs in epipelic form in circumneutral lake water at 6-15° C (42.9-59° F; Sahin and Akar 2005). Found in cold water (9.8° C, pH 7.35) in a calcareous Iowa fen (Shobe, Stoermer and Dodd 1963:Table 1, 2); in littoral zone of lakes (Stoermer 1962:93); on pond macrophytes (Troeger 1978).

Aulacoseira ambigua (Grunow) Simonsen (= *Melosira ambigua*; Fig. 7.8)
N = 29

Aquatic, in lakes and rivers; planktonic, alkaliphilic. On rocks from streams in Québec (Wunsam, Cattaneo and Bourassa 2002:Table 4). Planktonic form occurring at a weighted average pH of 7.4 in Connecticut lakes (Siver 1999:Table 1). Optimum salinity 0.09 g/l (range, 0.01-0.71) in lakes in British Columbia, Saskatchewan, and North Dakota (Wilson, Cumming and Smol 1996:Table 4). Optimum pH is 7.12 in German lakes and rivers (Schönfelder *et al*. 2002).

Aulacoseira angustissima [=*Aulacoseira granulata* v. *angustissima* (O. Müller) Simonsen]
N = 3

Aquatic, in lakes, streams, ponds; planktonic. Epiphytic on *Phragmites* stems (Müller 1999:Table 1). Planktonic in Lake Tanganyika (Caljon and Cocquyt 1992:136) and floodplain ponds in Argentina (Gabellone, Solari and Claps 2001).

Aulacoseira italica (Ehrenberg) Simonsen (Fig. 7.8)
N = 38

Aquatic, in lakes, streams, ditches; planktonic and periphytic; alkaliphilic. Epiphytic on *Phragmites* stems (Müller 1999:Table 1). Known to occur in overbank flood deposits (Medioli and Brooks 2003:Table 5). This species was characteristic of Carolina bays (ponds) with a short hydroperiod studied by Gaiser, Philippi and Taylor (1998:Table 3), suggesting it is adapted to desiccation.

Caloneis bacillum (Grunow) Mereschkowsky
N = 2

Aquatic, in lakes, rivers, bogs or other standing water. Alkaliphilous, fresh to brackish water, benthic habitats, often in running water (Hodgson, Vyverman and Tyler 1997); epipelic and aerophilous (Gasse 1986). Epilithic and epiphytic (O'Quinn and Sullivan 1983:Table 1). Found on bryophyte mat on wet sandstone (Lowe and Collins 1973:Table 1). Reported from sandstone cliff walls in Ohio (Casamatta *et al*. 2002:Table2). Found in cold and warm water (9.8-28.4° C, pH 7.35-7.95) in a calcareous Iowa fen (Shobe, Stoermer and Dodd 1963:Table 1, 2); in moss and lichens (Dodd and Stoermer 1962:Table 1). Bigler, Hall and Renberg (2000:Table 3) list optimum pH as >7.26 and optimum temperature as 12.2° C (54° F) for lakes in northern Sweden. Optimum pH is 7.98 in German lakes and rivers (Schönfelder *et al*. 2002). Has also been found in hot springs in Kenya at 41-46° C (107-115° F) and pH of 8.95-9.58 (Mpawenayo and

Mathooko 2004:Table 1, 2) and with optimum pH 7.29 ± 0.85, optimum temperature 29.15 ± 8.01° C (84.5° F) elsewhere in Kenya wetlands (Owen *et al*. 2004:Table 2). Optimum total phosphorus is 35.56 μg/l; optimum total nitrogen 3.55 mg/l (Winter and Duthie 2000:Table 3). A minor species in the Guadalupe River (Academy of Natural Sciences of Philadelphia 1991:VII-13).

Caloneis schumanniana (Grunow) Cleve (= *Caloneis lewisii*)
N = 1

Aquatic, found in littoral zone in standing, oligotrophic water with moderate electrolytes, abundant in carbonate-rich water. Found in cold and warm water (9.8-28.4° C, pH 7.35-7.95) in a calcareous Iowa fen (Shobe, Stoermer and Dodd 1963:Table 1, 2). Optimum pH is 7.52 in German lakes and rivers (Schönfelder *et al*. 2002). Found on submerged moss and sediment in Canadian Arctic lakes and ponds (Lim, Kwan and Douglas 2001:Table 1). Benthic in Lake Tanganyika lakebottom sediments (Caljon and Cocquyt 1992:148).

Cocconeis placentula Ehrenberg (Fig. 7.7)
N = 150

Aquatic, in lakes, streams, marshes; epiphytic and attached to any submerged surface. Optimum pH is about 8.0 (range, 4.7-8.6); indifferent to current, a littoral form and an early colonizer, alkaliphilic. In Pennsylvania, population density is correlated with water temperature and highest densities occur in the summer months when temperatures increase to about 23-27° C (73.4-80.6° F; Kindt and Small 2002:Table 1). Cosmopolitan, fresh to brackish water, colonizer of disturbed habitats, may be an indicator of a change from brackish to fresher water (Hodgson, Vyverman and Tyler 1997). In Florida fresh, hard-water springs, it is a pioneer species on bare surfaces such as young plant leaves (Whitford 1956:437), and it is a dominant species in such springs. Found in cold water

(9.8° C, pH 7.35) in a calcareous Iowa fen (Shobe, Stoermer and Dodd 1963:Table 1, 2). Optimum salinity 0.29-0.35 g/l (range, 0.02-5.6) for different varieties in lakes in British Columbia, Saskatchewan, and North Dakota (Wilson, Cumming and Smol 1996:Table 4). Has also been found in hot springs in Kenya at 41-46° C (107-115° F) and pH of 8.95-9.58 (Mpawenayo and Mathooko 2004:Table 1, 2). Found on bryophyte mat on wet sandstone (Lowe and Collins 1973:Table 1). Occurs abundantly at the Mustang Springs site (Winsborough 1995:Table 33). A form (var. *euglypta*) was reported to be one of the most abundant and persistent taxa in the Guadalupe River in sampling from 1955-1982, especially in cooler months (Academy of Natural Sciences of Philadelphia 1991:VII-13).

Craticula cuspidata (Kützing) Mann (= *Navicula cuspidata* var. *heribaudii*; Fig. 7.11)
N = 4

Aquatic and soil diatom; marshes, periphytic in lakes and ponds or benthic, epipelic, epilithic, alkaliphilic; can survive in hot springs up to 50° C; indifferent to salts and current; optimum pH 8.3-8.6 (Gasse 1986). Has been found in hot springs in Kenya at 41-46° C (107-115° F) and pH of 8.95-9.58 (Mpawenayo and Mathooko 2004:Table 1, 2). Optimum salinity 0.76 g/l (range, 0.07-8.24) in lakes in British Columbia, Saskatchewan, and North Dakota (Wilson, Cumming and Smol 1996:Table 4). Optimum pH is 7.89 in German lakes and rivers (Schönfelder *et al*. 2002). Found infrequently in dry lakes in Nevada (VanLandingham 1966:Table 1). Occurs abundantly at the Edmonson site (Winsborough 1995:Table 33).

Cyclotella meneghiniana Kützing
N = 1

Aquatic, in lakes, streams, swamps, thermal springs; tolerates high temperatures; tychoplanktonic or periphytic, halophilous (tolerates brackish water), alkaliphilous; abundant at pH of 7 to 8 or more; indifferent to current. On rocks from streams in

Québec (Wunsam, Cattaneo and Bourassa 2002:Table 4). Optimum salinity 1.37 g/l (range, 0.06-30.20) in lakes in British Columbia, Saskatchewan, and North Dakota (Wilson, Cumming and Smol 1996:Table 4). Optimum pH is 7.47 in German lakes and rivers (Schönfelder *et al*. 2002); pH near 8.6 (Gasse and Tekaia 1983:Table 6). Known to occur in overbank flood deposits (Medioli and Brooks 2003:Table 5), rarely in soil (Johansen 1999:268). Found in the Guadalupe River in sampling from 1958-1971, especially in the warmer months, late May through September (Academy of Natural Sciences of Philadelphia 1991:VII-14).

Cyclotella sp.
N = 1 not identifiable to species

Aquatic. The genus (species not identified) was characteristic of Carolina bays (ponds) with a relatively long hydroperiod studied by Gaiser, Philippi and Taylor (1998:Table 3).

Cymatopleura sp. (Fig. 7.9)
N = 5

Aquatic; the genus is common in epipelic (mud bottom) habitats in lakes, rivers, and wetlands (Lowe 2003:682).

Cymbella cistula (= *Cymbella neocistula* Krammer)
N = 2

Aquatic, in lentic habitats (marshes and lakes); periphytic, alkaliphilic. Epiphytic on *Phragmites* stems (Müller 1999:Table 1). Occurs in epipelic form in circumneutral lake water at 6-15° C (42.9-59° F; Sahin and Akar 2005). Antoniades, Douglas and Smol (2005:Table 3) list optimum pH of 7.8 and optimum dissolved organic carbon content of 7.31 mg/l for lakes and ponds in the Canadian Arctic. Optimum pH is 7.98 in German lakes and rivers (Schönfelder *et al*. 2002). Reported from peat bogs in Tierra del Fuego

(pH, 4.3-6.8; Mataloni 1999:Tables 1, 2). Optimum salinity 0.50 g/l (range, 0.07-3.67) in lakes in British Columbia, Saskatchewan, and North Dakota (Wilson, Cumming and Smol 1996:Table 4), where it is rare. Reported from the San Marcos River (Sherwood and Sheath 1999:Table 3). Occurs abundantly at the Mustang Springs site (Winsborough 1995:Table 33).

Cymbella mexicana (Ehrenberg) Cleve (Fig. 7.8)
N = 14

Aquatic, in lentic habitats (marshes and lakes); attached. The variety *C. m. mexicana* is found in both stagnant water and on submerged rocks in running water (Terao, Mayama and Kobayasi 1993). Forms spring blooms in lakes in Washington (Castenholz 1960). Optimum specific conductance is 114 ± 12 μS/cm, optimum inorganic nitrogen 0.07 ± 0.01 mg/l (Leland, Brown and Mueller 2001:Table 6).

Cymbella sp. (Fig. 7.9)
N = 24 not identifiable to species

Denticula elegans Kützing
N = 74

Aquatic or aerophilous, in marshes, lakes and streams, wet walls; periphytic; found in thermal streams, playas, and dry lakes; an early colonizer of warm springs; a littoral form. The genus occurs most abundantly in benthic hardwater habitats (Lowe 2003:676); optimum pH is about 8 (range, 7-8). Found in long chains attached to plants in standing water. Found in warm water (28.4° C, pH 7.95) in a calcareous Iowa fen (Shobe, Stoermer and Dodd 1963:Table 1, 2). Prefers high conductivity warm water, but also found on submerged moss, rocks and sediment in Canadian Arctic lakes and ponds (Lim, Kwan and Douglas 2001:Table 1). Found at 33° C in Yellowstone hot springs (Stockner

1967:Table 1). Reported from sandstone cliffs in Ohio (Casamatta *et al*. 2002:Table2). Abundant at most southern Plains sites discussed by Winsborough (1995:Table 33).

Denticula cf. *D. kuetzingii* Grunow (Fig. 7.10)
N = 13

Aquatic, in lakes and streams, alkaliphilic. Occurs abundantly at the Mustang Springs site (Winsborough 1995:Table 33). Antoniades, Douglas and Smol (2005:Table 3) list optimum pH of 8.2 and optimum dissolved organic carbon content of 4.73 mg/l for lakes and ponds in the Canadian Arctic. Optimum salinity 0.23 g/l (range, 0.03-1.91) in lakes in British Columbia, Saskatchewan, and North Dakota (Wilson, Cumming and Smol 1996:Table 4), where it is particularly abundant. Found on submerged moss, rocks and sediment in Canadian Arctic lakes and ponds (Lim, Kwan and Douglas 2001:Table 1).

Diadesmis aerophila (Krasske) D. G. Mann (= *Navicula aerophila*; Fig. 7.11)
N = 2

Aerophilous, in soil and carbonate-rich moss. Reported from sandstone cliff walls in Ohio (Casamatta *et al*. 2002:Table2).

Diadesmis gallica W. Smith (= *Navicula gallica*; Fig. 7.11)
N = 10

Aerophile, in damp rocks or moss. Variety *perpusilla* reported as a soil diatom in France (Bérard *et a*l. 2004:Table 3), found in peat bogs in Tierra del Fuego (Mataloni 1999:Table 2) and lakes in Antarctica (Fumanti, Cavacini and Alfinito 1997:Table 3). Reported (as *Navicula gallica*) from sandstone cliffs in Ohio (Casamatta *et al*. 2002:Table2) and streams in the Canadian high Arctic (Antoniades and Douglas 2002:Table 2). Occurs abundantly at the Clovis site and Mustang Springs (Winsborough 1995:Table 33).

Diploneis elliptica (Kützing) Cleve (Fig. 7.9)
N = 9

Aquatic, lakes and streams; alkaliphilic. Characteristic of brackish to fresh water, benthic habitats (Hodgson, Vyverman and Tyler 1997); bogs, lakes and springs (Gasse 1986); warm springfed ponds and wet meadows (St. Clair and Rushforth 1977:369); aerophilic or epipelic, indifferent to salt, may be in acid waters (Campeau, Pienitz and Héquette 1999). Optimum pH is 7.69 in German lakes and rivers (Schönfelder *et al*. 2002); 5.0-6.9 in East Africa (Gasse and Tekaia 1983:Table 6). Reported from sandstone cliff walls in Ohio (Casamatta *et al*. 2002:Table2).

Diploneis petersenii Hustedt
N = 3

Aerophilous, in moss and peat. Epipelic, found at depth in oligotrophic, hard water lakes (Lowe 1996:Table 1).

Epithemia adnata (Kützing) Brébisson (Figs. 7.8, 7.14)
N = 546

Aquatic, in marshes, lakes and streams; epiphytic, alkaliphilic. Epiphytic on *Phragmites* stems (Müller 1999:Table 1). On rocks from streams in Québec (Wunsam, Cattaneo and Bourassa 2002:Table 4). According to Lowe (2003:681), "*Epithemia* is to be found in benthic hard-water habitats reaching maximum abundance in microhabitats where phosphorus is relatively more available (low N/P microhabitats) such as the surface of submerged aquatic plants." Indifferent to current and pH (optimum 7, range 6.4-8.5); prefers sulfate and chloride–rich water of spring-fed ponds and small streams; a littoral form. Optimum salinity 0.5 g/l (Cumming and Smol 1993); fresh to brackish waters (Hodgson, Vyverman and Tyler 1997). Optimum salinity 1.09 g/l (range, 0.30-3.91) in lakes in British Columbia, Saskatchewan, and North Dakota (Wilson, Cumming and

Smol 1996:Table 4). Optimum pH is 7.97 in German lakes and rivers (Schönfelder *et al*. 2002). Has also been found in hot springs in Kenya at 41-46° C (107-115° F) and pH of 8.95-9.58 (Mpawenayo and Mathooko 2004:Table 1, 2). Benthic in Lake Tanganyika bottom sediments (Caljon and Cocquyt 1992:149). The sixth most abundant diatom species in the bench deposits. Abundant at the Clovis site (Winsborough 1995:Table 33); reported at 41 GD 21 by Robinson (1979:112).

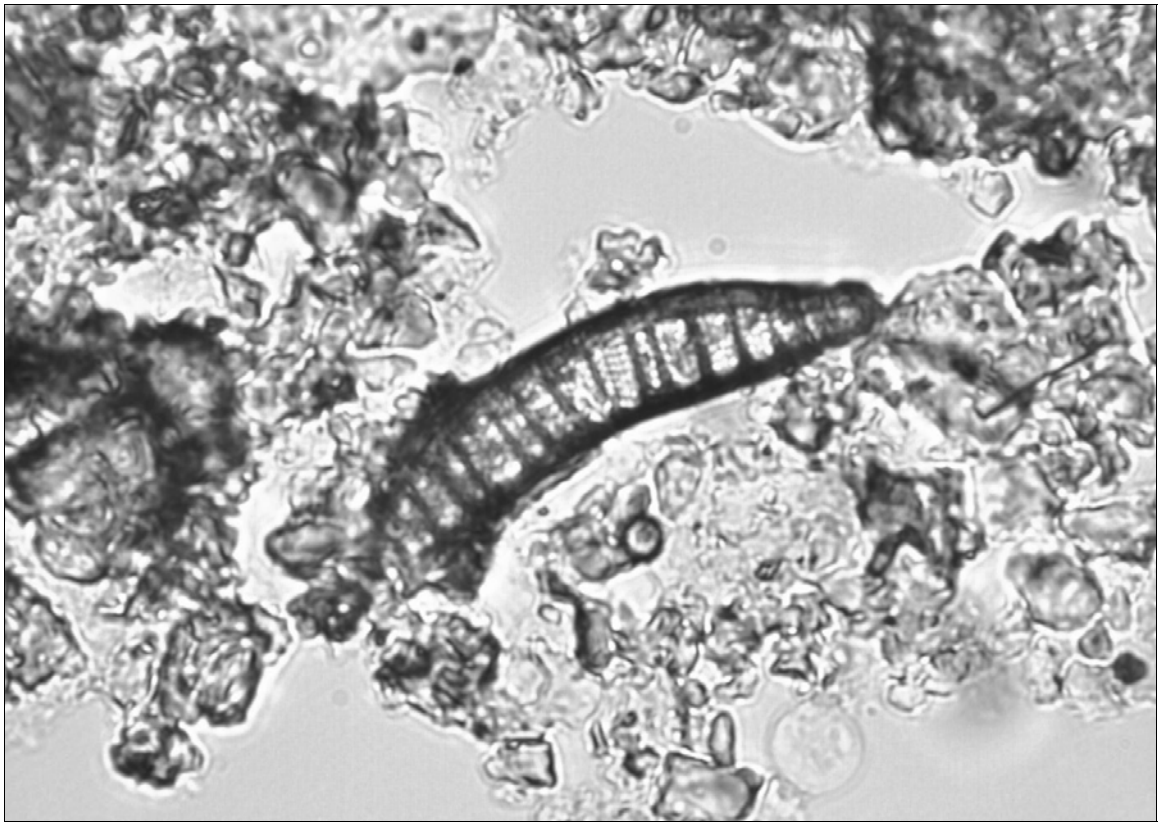

Figure 7.14. *Epithemia* sp., Probably *E. adnata*. Diatom sample 23; N110 E102 (91.85-91.80 m), stratum 1, 50X lens.

Epithemia argus (Ehrenberg) Kützing
N = 2

Aquatic, in marshes, lakes and streams; epiphytic, alkaliphilic. Extremely tolerant of osmotic stress from desiccation (Robinson 2004). Prefers water with moderate to high $CaCO_3$ content in streams, lakes and ponds (Patrick and Reimer 1975); pH 8.6-10.9 (Gasse and Tekaia 1983:Table 6). Found in warm water (28.4° C, pH 7.95) in a calcareous Iowa fen (Shobe, Stoermer and Dodd 1963:Table 1, 2); in ponds and wet meadows in Utah (St. Clair and Rushforth 1977:383), dry lakes in Nevada (VanLandingham 1966:Table 1, 234). Optimum salinity 0.95 g/l (range, 0.13-6.90) in lakes in British Columbia, Saskatchewan, and North Dakota (Wilson, Cumming and Smol 1996:Table 4). Has also been found in hot springs in Kenya at 41-46° C (107-115° F) and pH of 8.95-9.58 (Mpawenayo and Mathooko 2004:Table 1, 2). This species, rare at Berger Bluff, is much more widespread and abundant at the southern Plains sites discussed by Winsborough (1995:Table 33).

Epithemia turgida (Ehrenberg) Kützing (Figs. 7.8, 7.15)
N = 2329

Aquatic, in marshes, lakes and streams; epiphytic, alkaliphilic; optimum pH around 8.2 (range, 4.6-9.0) tolerant of osmotic stress, occurs both in clean and polluted water. Optimum pH is 7.57 in German lakes and rivers (Schönfelder *et al*. 2002). Optimum salinity 0.4 g/l (Cumming and Smol 1993). Epiphytic, oligohalobous to salt-indifferent, alkaliphilous (Ehrlich 1995). Prefers little or no current; a littoral form of shallow ponds and lakes. Epiphytic on *Phragmites* stems (Müller 1999:Table 1). The single most abundant diatom species in the bench deposits. Occurs abundantly at the Lubbock Lake, Gibson, Tolk, Edmonson, and Flagg sites (Winsborough 1995:Table 33).

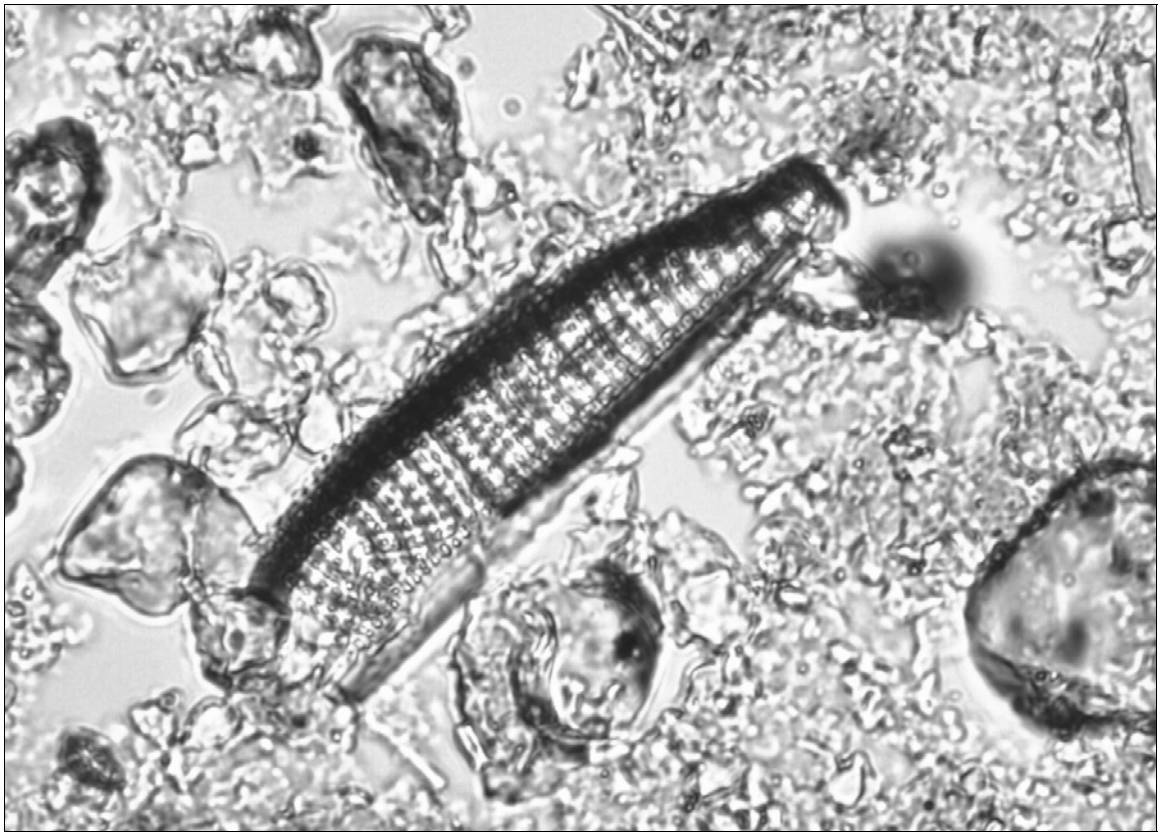

Figure 7.15. *Epithemia turgida*. Diatom sample 16; N110 E102 (92.20-92.15 m), basal stratum 2B, 50X lens.

Epithemia sp.
N = 5 not identifiable to species

Eunotia cf. *E. pectinalis* (Dillwyn) Rabenhorst (Fig. 7.8)
N = 17

Aquatic, in lakes and streams; epiphytic; pH indifferent to acidophilous. Found on rocks from streams in Québec (Wunsam, Cattaneo and Bourassa 2002:Table 4). As phytoplankton in open water of lakes in Ontario (pH 4.6-7.0; Stokes and Yung 1986:Table 8). Found in springs and seeps in North Carolina piedmont and coastal plain; on coastal plain creeks, abundantly forms ribbons up to several centimeters long in late winter and spring; grows best attached in cool, brown, slowly moving water; also fairly

abundant in the summer; occurs as a pioneer on wood and plant surfaces (Whitford and Schumacher 1963:148, 155, Table 1). Abundant in North Carolina streams in cool seasons, at about 15-22° C and in late winter in neutral seeps (Whitford and Schumacher 1968:231, Table 1). As epiphytes in deep, oligotrophic lakes (Hawes and Schwarz 1996). Optimum pH 6.76 ± 0.37, optimum temperature 24.69 ± 4.16° C (76.4° F) in Kenya swamps and marshes (Owen *et al*. 2004:Table 2). Rare in the Guadalupe River (Academy of Natural Sciences of Philadelphia 1991:VII-15). Benthic in Lake Tanganyika lakebottom sediments (Caljon and Cocquyt 1992:146).

Fragilaria capitata (Ehrenberg) Lange-Bertalot (= *Synedra capitata*; Fig. 7.8)
N = 11

Aquatic, attached form. Occurs abundantly at the Gibson site, but absent or rare at most of the other southern Plains sites discussed by Winsborough (1995:Table 33).

Fragilaria capucina var. *vaucheriae* (Kützing) Lange-Bertalot (= *Fragilaria vaucheriae* var. *capucina*; Fig. 7.11)
N = 12

Aquatic; prefers slightly alkaline water; indifferent to small amounts of calcium chloride. Optimum pH is 7.92 in German lakes and rivers (Schönfelder *et al*. 2002). Epiphytic on *Phragmites* stems (Müller 1999:Table 1). Found on submerged moss and rocks in Canadian Arctic lakes and ponds (Lim, Kwan and Douglas 2001:Table 1) and on pebble-cobble bottom sediment of White Creek, New York (Passy 2001:Table 1), chiefly in low-velocity current locations.

Fragilaria elliptica Schumann (Fig. 7.10)
N = 2

Aquatic. Found in lake bottom sediment in the Sierra Nevada, California (Bloom *et al*. 2003:Appendix A) and in soil in Greenland (van Kerckvoorde *et al*. 2000:Appendix 1).

Fragilaria tenera (W. Smith) Lange-Bertalot
N = 1

Aquatic, in lakes and streams; attached. On rocks from streams in Québec (Wunsam, Cattaneo and Bourassa 2002:Table 4). Optimum salinity 0.32 g/l (range, 0.01-8.07) in lakes in British Columbia, Saskatchewan, and North Dakota (Wilson, Cumming and Smol 1996:Table 4). Optimum pH is 8.62 in German lakes and rivers (Schönfelder *et al*. 2002). Optimum total phosphorus is 53.95 μg/l; optimum total nitrogen 2.63 mg/l (Winter and Duthie 2000:Table 3).

Fragilaria ulna (Nitzsch) Lange-Bertalot (= *Synedra ulna*; Figs. 7.8, 7.16)
N = 557

Aquatic, cosmopolitan, in streams, rivers, lakes, creeks, ditches, marshes, bogs and ponds. Attaches to plants, wood and stones, or suspended in the water column with distribution current-dependant. On sandstone cliff walls in Ohio (Casamatta *et al*. 2002:Table2) and pebble-cobble bottom sediment of White Creek, New York (Passy 2001:Table 1), chiefly in higher-velocity current. Epiphytic on *Phragmites* stems (Müller 1999:Table 1). A warm water form usually found at temperatures over 30° C, but also recorded from cool water; an Idaho study found it most abundant at about 22-39° C (Vinson and Rushforth 1989:Fig. 6). Dominant species in Florida fresh, hard-water springs (Whitford 1956:437). Prefers dirty flowing water; common in high nitrate concentrations, tolerates small amounts of salts. Alkaliphilic; optimum pH 6.4-8.3 (range, 5.7-9.0). Occurs at a weighted average pH of 7.6 in Connecticut lakes (Siver 1999:Table 1). Optimum salinity 0.4 g/l (Cumming and Smol 1993). Cosmopolitan, fresh to fresh-brackish water (Hodgson, Vyverman and Tyler 1997). Optimum salinity 0.42 g/l (range, 0.04-4.31) in lakes in British Columbia, Saskatchewan, and North Dakota ("*Fragilaria ulna* complex," Wilson, Cumming and Smol 1996:Table 4). Has also been found (as

Synedra ulna) in hot springs in Kenya at 41-46° C (107-115° F) and pH 8.95-9.58 (Mpawenayo and Mathooko 2004:Table 1, 2) and with optimum pH 6.95 ± 0.62, optimum temperature 25.87 ± 5.48° C (78.6° F) elsewhere in Kenya wetlands (Owen *et al*. 2004:Table 2). The fifth most abundant diatom in the bench deposits. Occurs abundantly at the Gibson, Tolk, and Mustang Springs sites (Winsborough 1995:Table 33). Found mostly in low abundance in the Guadalupe River in sampling 1958-1980, in cooler months, late November to mid-March (Academy of Natural Sciences of Philadelphia 1991:VII-28). Species was present in almost 17% of the US rivers evaluated by Potapova and Charles (2002:Table 2).

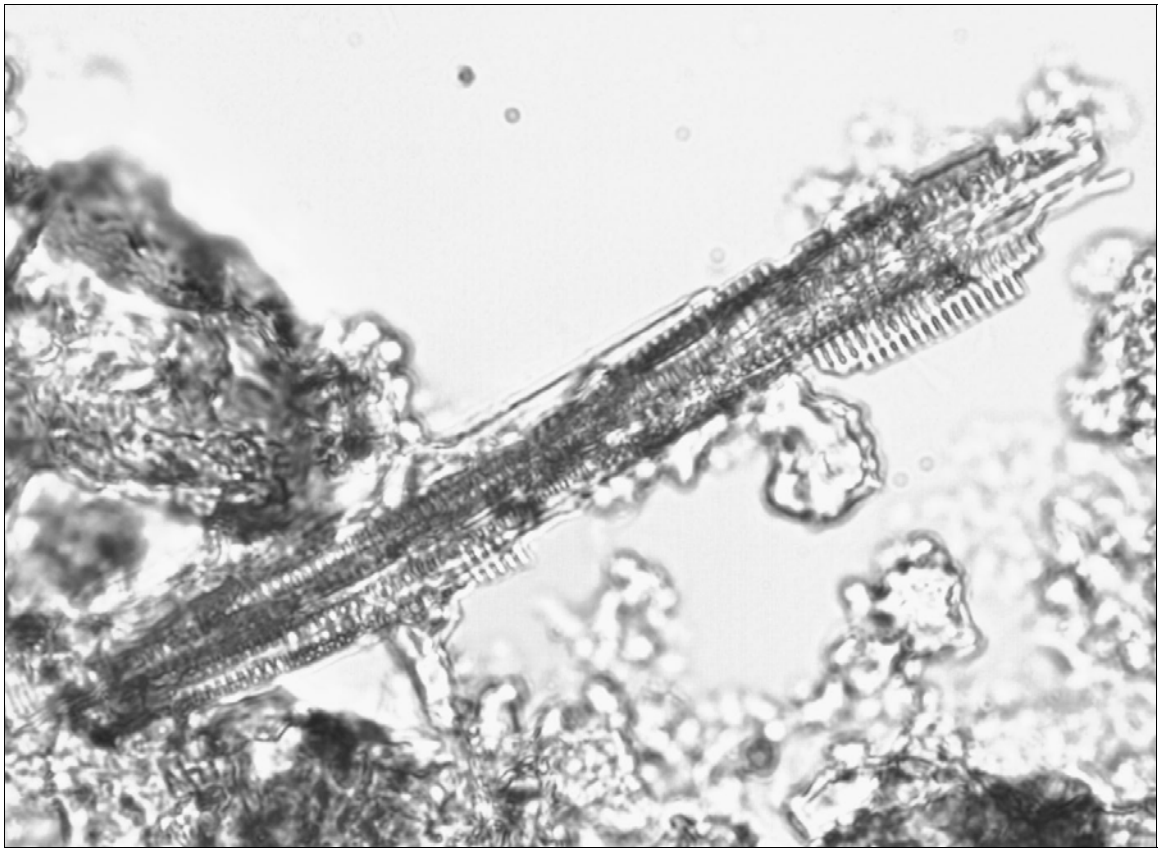

Figure 7.16. *Fragilaria ulna* Fragment. Diatom sample 19; N110 E102 (92.05-92.00 m), stratum 2A, 50X lens.

Gomphonema acuminatum Ehrenberg
N = 1

Aquatic, in lakes and streams; epiphytic, alkaliphilic. The genus is cosmopolitan (Kociolek and Spaulding 2003:665). Unable to survive exposure and desiccation (Evans 1958:162). Epiphytic (O'Quinn and Sullivan 1983:Table 1). Rare in the Guadalupe River (Academy of Natural Sciences of Philadelphia 1991:VII-16). Attached, oligohalobous (Zalat 2003). Bigler, Hall and Renberg (2000:Table 3) list optimum pH as 7.17 for lakes in northern Sweden. Optimum pH is 7.23 in German lakes and rivers (Schönfelder *et al*. 2002). Optimum salinity 0.18 g/l (range, 0.06-0.56) in lakes in British Columbia, Saskatchewan, and North Dakota (Wilson, Cumming and Smol 1996:Table 4).

Gomphonema affine Kützing (Fig. 7.10)
N = 2

Aquatic, fresh to brackish water. Benthic in Lake Tanganyika lakebottom sediments (Caljon and Cocquyt 1992:146). Occurs abundantly at Mustang Springs (Winsborough 1995:Table 33). Found in the Guadalupe River (Academy of Natural Sciences of Philadelphia 1991:VII-16), especially in the cooler months.

Gomphonema angustum Agardh (Fig. 7.10)
N = 2

Aquatic, in lakes and streams; epiphytic. Found at the Wilson-Leonard site (Winsborough 1998b:Table 38-2). Optimum salinity 0.29 g/l (range, 0.04-1.99) in lakes in British Columbia, Saskatchewan, and North Dakota (Wilson, Cumming and Smol 1996:Table 4). Optimum pH is 8.39 in German lakes and rivers (Schönfelder *et al*. 2002). Benthic in Lake Tanganyika lakebottom sediments (Caljon and Cocquyt 1992:150).

Gomphonema parvulum Kützing
N = 4

Aquatic, in streams, lakes, ponds, and ditches; cosmopolitan; found in the San Marcos River, Comal River (Sherwood and Sheath 1999:Table 3) and Little River (Winsborough 2001:Table H-2). Present, often abundantly, in the Guadalupe River, generally in cooler periods (Academy of Natural Sciences of Philadelphia 1991:VII-17). A study in Idaho found it eurythermic but most abundant at about 22° C (71.6° F; Vinson and Rushforth 1989:Fig. 6). This species was present in 41% of the US rivers evaluated by Potapova and Charles (2002:Table 2). Found in damp pond-margin leaf litter (Evans 1960). Optimum salinity 0.2 g/l (Cumming and Smol 1993). Epipelic and epilithic (Czarnecki 1979). Attached form, pH and salt indifferent, found usually in running water but sometimes in standing water (Haworth 1977). Abundant in attached form during the spring in coastal plain creeks in North Carolina (Whitford and Schumacher 1963:155). Sherwood and others (2000:146) found it negatively correlated with stream velocity and day length. Epiphytic (O'Quinn and Sullivan 1983:Table 1); found on submerged macrophytes in ponds in Oklahoma (Troeger 1978:Table 2). Epiphytic on *Phragmites* stems (Müller 1999:Table 1). On rocks from streams in Québec (Wunsam, Cattaneo and Bourassa 2002:Table 4). Bigler, Hall and Renberg (2000:Table 3) list optimum pH as 6.69 and optimum temperature as 11.0° C (51.8° F) for lakes in northern Sweden. Reported from peat bogs in Tierra del Fuego (pH, 4.4-6.8; Mataloni 1999:Tables 1, 2). Has also been found in hot springs in Kenya at 41-46° C (107-115° F) and pH of 8.95-9.58 (Mpawenayo and Mathooko 2004:Table 1, 2) and with optimum pH 6.74 ± 0.38, optimum temperature 33.62 ± 6.48° C (92.4° F) elsewhere in Kenya wetlands (Owen *et al*. 2004:Table 2). Found occasionally on sandstone cliffs wet by seepage in Kentucky (Camburn 1982:Table 1) and Ohio (Casamatta *et al*. 2002:Table2).

Gomphonema sp.
N = 1 not identifiable to species

Hantzschia amphioxys (= *Hantzschia abundans* Lange-Bertalot; Figs. 7.7, 7.17)
N = 1303

A common soil diatom with global distribution, but can also occur in temporary aquatic habitats. The third most abundant diatom in the bench deposits. Aerophilous, found in soil, mosses, calcareous dunes, dry lakes, rainwater pools, wet walls. The most important common and widespread soil diatom, found living in soils to 1 m depth, can survive drought for up to three years. Also occurs in windblown diatom assemblages. Maximum growth rates occur with daytime air temperatures of 22° C (71.6° F), nighttime 16° C (60.8° F), day length 14 hours (Edenhofner and Schmid 1984). In aquatic habitats, it is alkaliphilic, optimum pH 7.8-8.0 (range, 5.4-9.2), occurs in salt concentrations of less than 500 mg/l, fresh to brackish water; found mainly in shallow waters, small ponds. Optimum pH 7.20 in German lakes and rivers (Schönfelder *et al*. 2002). Optimum salinity 4.62 g/l (range, 0.15-139.64) in lakes in British Columbia, Saskatchewan, and North Dakota (Wilson, Cumming and Smol 1996:Table 4), suggesting it can tolerate high salt concentrations. Not common in permanent water. This species was characteristic of Carolina bays (ponds) with a relatively short hydroperiod studied by Gaiser, Philippi and Taylor (1998:Table 3), suggesting it is adapted to desiccation. Found in damp pond-margin leaf litter (Evans 1960). Evans (1958:162) found it frequent only upon rewetting after drought. Found on bryophyte mat on wet sandstone (Lowe and Collins 1973:Table 1), occasionally on sandstone cliffs wet by seepage in Kentucky (Camburn 1982:Table 1); in moss and lichens in Iowa (Dodd and Stoermer 1962:Table 1), peat bogs in Tierra del Fuego (pH, 4.3-6.8; Mataloni 1999:Tables 1, 2); in warm ponds, streams, wet meadows and rocks in Utah (St. Clair and Rushforth 1977:384); also in hot springs in

Kenya at 41-46° C (107-115° F) and pH of 8.95-9.58 (Mpawenayo and Mathooko 2004:Table 1, 2). Found in fairly large numbers in overbank flood deposits (Medioli and Brooks 2003:Table 5 and Appendix A) and the Lino site in Webb County (Winsborough 2002b:Table H-2) but absent or uncommon at other southern Plains sites discussed by Winsborough (1995:Table 33).

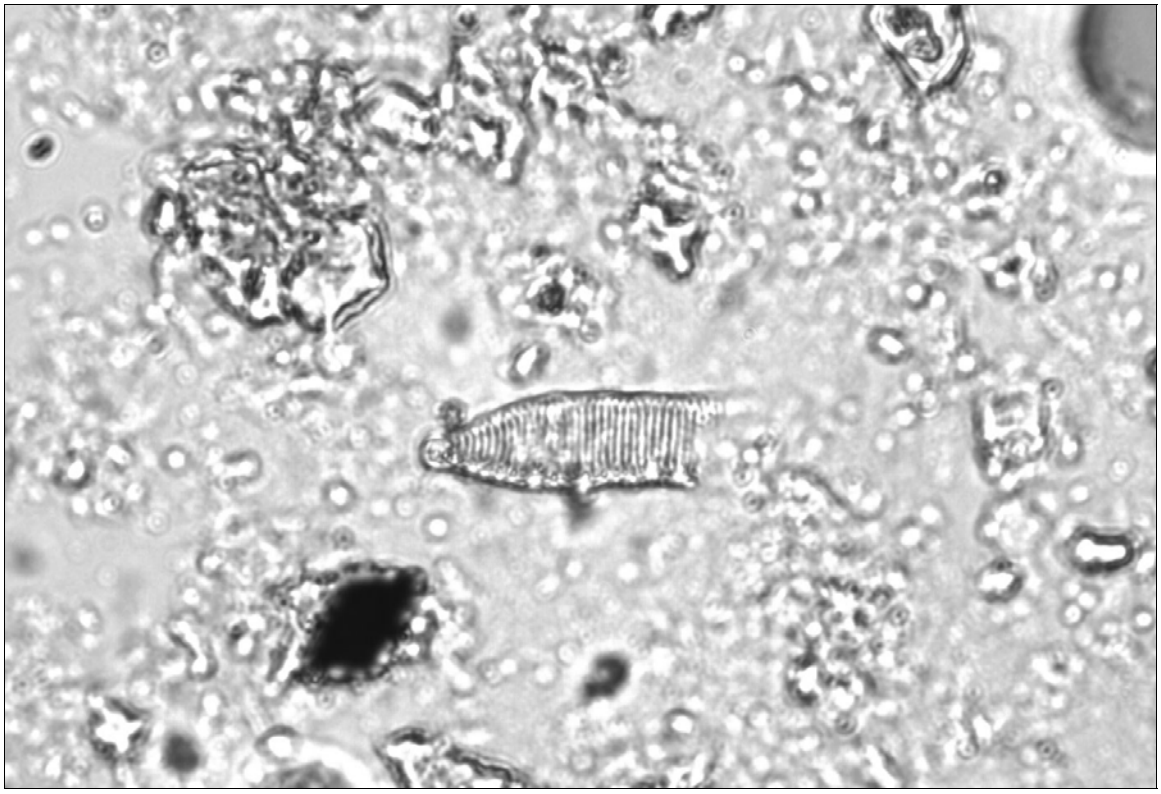

Figure 7.17. *Hantzschia amphioxys* Fragment. Diatom sample 28; N110 E102 (91.60-91.55 m), lowest sample in stratum 1, 50X lens.

Luticola goeppertiana (Bleisch) D. G. Mann (= *Navicula goeppertiana*)
N = 3

Aerophile and aquatic, a soil diatom; alkaliphilic, pollution-tolerant. Periphytic in water with moderate mineral content (but not brackish); tolerates high levels of pollution; can be aerophilous (Ehrlich 1995).

Luticola mutica (Kützing; = *Navicula mutica*; Fig. 7.7)
N = 909

Both aerophilic and aquatic, a soil diatom; alkaliphilic. Found on wet walls, mosses, springs, intermittent streams, dry lakes, attached to rocks and plants. One of the most widespread soil diatoms, found living to a depth of 1.3 m. More abundant in sandy than in silty or clayey soil (Hayek and Hulbary 1956:Table 1). Occurs abundantly in dry lakebottom sediment in Nevada (VanLandingham 1966:Table 1, 231). Found on bryophyte mat on wet sandstone (as *Navicula mutica*; Lowe and Collins 1973:Table 1). Found occasionally on sandstone cliffs wet by seepage in Kentucky (Camburn 1982:Table 1);); in moss and lichens in Iowa (Dodd and Stoermer 1962:Table 1). In aquatic habitats, found in fresh, brackish and alkaline water (optimum pH 7.5-8.5; range 6.5-8.5); current indifferent; characteristic of well-oxygenated water but also abundant in water subject to periods of desiccation. Occurs in salt concentrations of less than 500 mg/l. Optimum salinity 5.79 g/l (range, 0.59-56.89) in lakes in British Columbia, Saskatchewan, and North Dakota (as *Navicula mutica*; Wilson, Cumming and Smol 1996:Table 4). Has also been found (as *Navicula mutica*) in hot springs in Kenya at 41-46° C (107-115° F) and pH of 8.95-9.58 (Mpawenayo and Mathooko 2004:Table 1, 2). Benthic in Lake Tanganyika lakebottom sediments (Caljon and Cocquyt 1992:151). Periphytic to tychoplanktonic in springs and streams, aerophilous in soil, tolerates wide range of salt and pH (Ehrlich 1995). Optimal water depth 0.3 m (Campeau, Pienitz and Héquette 1999). Salt and current indifferent, alkaliphilous (Haworth 1977). Found in overbank flood deposits (Medioli and Brooks 2003:Appendix A, B). The fourth most abundant diatom in the bench deposits, but absent or uncommon at southern Plains sites discussed by Winsborough (1995:Table 33).

Luticola nivalis (Ehrenberg) D. G. Mann (= *Navicula mutica* undifferentiated; Fig. 7.11)
N = 3

Aerophile, in soil, moss and other damp habitats. Periphytic or aerophilous in periodically wet environments (Ehrlich 1995).

Mastogloia smithii Thwaites (Fig. 7.9)
N = 9

Aquatic, in ponds, streams and lakes; benthic, alkaliphilic. Optimum salinity 0.89 g/l (range, 0.03-30.90) in lakes in British Columbia, Saskatchewan, and North Dakota (Wilson, Cumming and Smol 1996:Table 4). Optimum pH is 8.38 in German lakes and rivers (Schönfelder *et al*. 2002). Has also been found in hot springs in Kenya at 41-46° C (107-115° F) and pH of 8.95-9.58 (Mpawenayo and Mathooko 2004:Table 1, 2). Variety *lacustris* found in wet meadows and on vegetation along pond and stream banks in Utah (St. Clair and Rushforth 1977:367).

Melosira varians Agardh (Fig. 7.11)
N = 7

Aquatic, in lakes, ponds, streams, ditches; periphytic, alkaliphilic. The most common species in the genus, often abundant in eutrophic streams; usually benthic, but also associated with planktonic forms (Stoermer and Julius 2003:583). Found on pebble-cobble bottom sediment of White Creek, New York (Passy 2001:Table 1), chiefly in low-velocity current locations. Abundant in a turbid, high-velocity river (Soinenen 2003). Epiphytic on *Phragmites* stems (Müller 1999:Table 1). Unable to survive exposure and desiccation (Evans 1958:162). Epiphytic (O'Quinn and Sullivan 1983:Table 1). Found occasionally on sandstone cliffs wet by seepage in Kentucky (Camburn 1982:Table 1). Optimum pH is 8.10 in German lakes and rivers (Schönfelder *et al*. 2002); 7.0-7.9 in east Africa (Gasse and Tekaia 1983:Table 6). Occurs in Little River (Winsborough

2001:Table H-2). Found in sampling 1958-1982 in the Guadalupe River, more abundant in cooler periods, December to April (Academy of Natural Sciences of Philadelphia 1991:VII-18). This species was present in 24% of the US rivers evaluated by Potapova and Charles (2002:Table 2).

Meridion circulare var. *constrictum* (Ralfs) Van Heurck (Fig. 7.10)
N = 1

Aquatic, in lakes, ponds, rivers, springs and streams; periphytic or planktonic; alkaliphilic. Epiphytic (O'Quinn and Sullivan 1983:Table 1). Occurs in the San Marcos River (Sherwood and Sheath 1999:Table 3). In North Carolina, *Meridion circulare* (no variety specified) is a low temperature (about 15° C), low-light species occurring in abundance only in winter (Whitford and Schumacher 1968:232, Table 1); widespread in bottom ooze in rivers. This species was characteristic of Carolina bays (ponds) with a short hydroperiod studied by Gaiser, Philippi and Taylor (1998:Table 3), suggesting it is adapted to desiccation. Found occasionally on sandstone cliffs wet by seepage in Kentucky (Camburn 1982:Table 1) and Ohio (Casamatta *et al*. 2002:Table2). Optimum pH is 7.24 in German lakes and rivers (for the species but not the variety; Schönfelder *et al*. 2002). Keithan and Lowe (1985:66) found the genus *Meridion* more abundant in slow-current areas.

Muelleria gibbula (Cleve) Spaulding and Stoermer (= *Navicula gibbula*)
N = 2

Aerophile or aquatic, on damp rocks, mosses, or in temporary pools of water (Kociolek and Spaulding 2003:649). Widespread in softwater, shallow water, soil and aerophilic habitats, especially in Arctic regions, but also in Maryland, South Carolina, Utah, Washington, and Wyoming (Spaulding, Kociolek and Wong 1999), associated with mosses and in ephemeral pools in the Midwest and West (Kociolek and Spaulding

2003:649). Recovered (as *Navicula gibbula*) from benthic algal mats on lakeshores in Antarctica (Fumanti, Cavacini and Alfinito 1997:Table 3).

Navicula elginensis (Gregory) Ralfs
N = 3

Aquatic, in temporary pools, ponds and streams; tolerant of a wide range of conditions in fresh to slightly brackish water. Cosmopolitan in brackish-fresh water (Hodgson, Vyverman and Tyler 1997). Found on submerged macrophytes in ponds in Oklahoma (Troeger 1978:Table 2). Optimum total phosphorus is 9572 μg/l; optimum total nitrogen 2.43 mg/l (Winter and Duthie 2000:Table 3). Variety *rostrata* found in wet meadows in Utah (St. Clair and Rushforth 1977:371).

Navicula muticopsis [= *Luticola muticopsis* (Van Heurck) D. G. Mann; Fig. 7.9]
N = 24

Both aerophilic and aquatic, a soil diatom; alkaliphilic. Found in temporary pools and waterfalls. A widespread species in Antarctica, where it is found in benthic algal mats (Fumanti, Cavacini and Alfinito 1997:Table 3).

Navicula oblonga (Kützing) Kützing (Fig. 7.9)
N = 6

Aquatic, primarily in standing alkaline waters with high electrolyte content or brackish water; epipelic, tolerates low oxygen and high pollution. Optimum salinity 0.47 g/l (range, 0.08-2.61) in lakes in British Columbia, Saskatchewan, and North Dakota (Wilson, Cumming and Smol 1996:Table 4). Optimum pH is 8.21 in German lakes and rivers (Schönfelder *et al*. 2002). Has also been found in hot springs in Kenya at 41-46° C (107-115° F) and pH of 8.95-9.58 (Mpawenayo and Mathooko 2004:Table 1, 2). Benthic

and euryhaline in Lake Tanganyika lakebottom sediments (Caljon and Cocquyt 1992:151). In wet meadows and ponds in Utah (St. Clair and Rushforth 1977:372).

Navicula placentula (Ehrenberg) Kützing
N = 1

Aquatic, in lakes and streams; alkaliphilic. Optimum pH is 8.33 in German lakes and rivers (Schönfelder *et al*. 2002). Listed as "aerophytic" (Caljon and Cocquyt 1992:152).

Navicula texana (= *Navicula kotschyi* Grunow)
N = 3

Aquatic, in ponds, lakes and streams; alkaliphilic. Found in the Guadalupe River in warm months, August to October (Academy of Natural Sciences of Philadelphia 1991:VII-22). Originally described from the Seguin area, on filamentous green algae, hard water (Patrick 1966:445).

Neidium affine var. *longiceps* (Gregory) Cleve
N = 3

Aquatic, in lakes and rivers, acidophilic. In a single sample of phytoplankton in open water of lakes in Ontario (pH 4.6-7.0; Stokes and Yung 1986:Table 8). The species (variety not specified) has been found in hot springs in Kenya at 41-46° C (107-115° F) and pH of 8.95-9.58 (Mpawenayo and Mathooko 2004:Table 1, 2).

Neidium sp. (Fig. 7.11)
N = 4 not identifiable to species

Nitzschia amphibia Grunow (Fig. 7.7)
N = 113

Aquatic or aerophilic, widespread, cosmopolitan, in marshes, lakes, ponds and streams, playas and dry lakes; or on wet walls, in mud and attached to plants, rocks, and wood;

alkaliphilic (optimum pH 8.5; range, 4.0-9.3). Found on bryophyte mat on wet sandstone (Lowe and Collins 1973:Table 1). Reported from sandstone cliff walls in Ohio (Casamatta *et al*. 2002:Table2). Epiphytic and epilithic (O'Quinn and Sullivan 1983:Table 1). Found occasionally on sandstone cliffs wet by seepage in Kentucky (Camburn 1982:Table 1). Found in cold water (9.8° C, pH 7.35) in a calcareous Iowa fen (Shobe, Stoermer and Dodd 1963:Table 1, 2). Common in springs and abundant in hot springs (optimum temperature 20-30° C; occurs over a maximum range of 15°); prefers warm, brackish, sodium sulfate water. Tolerates relatively large amounts of nitrate and phosphate, and can grow in poorly oxygenated water. Found in littoral zone of slightly alkaline lakes; current indifferent. Planktonic and epipelic in the littoral mud of freshwater lakes, can tolerate higher salt, slight fluctuation in osmotic pressure, seems to prefer slightly alkaline water with medium pH; tolerates wide temperature range, found in hot springs (Gasse 1986); found in hot springs in Kenya at 41-46° C (107-115° F) and pH of 8.95-9.58 (Mpawenayo and Mathooko 2004:Table 1, 2). Optimum salinity 0.58 g/l (range, 0.04-8.59) in lakes in British Columbia, Saskatchewan, and North Dakota (Wilson, Cumming and Smol 1996:Table 4). Reported from peat bogs in Tierra del Fuego (pH, 6.6-6.8; Mataloni 1999:Tables 1, 2). Occurs abundantly at Lubbock Lake, the Clovis site, the Gibson site, and Mustang Springs (Winsborough 1995:Table 33). Found consistently in the Guadalupe River, sometimes abundantly, in sampling 1956-1982 River; less abundant from late November to March (Academy of Natural Sciences of Philadelphia 1991:VII-24). This species was present in 33% of the US rivers evaluated by Potapova and Charles (2002:Table 2). Antoniades, Douglas and Smol (2005:Table 3) list optimum pH of 8.3 and optimum dissolved organic carbon content of 2.27 mg/l for lakes and ponds in the Canadian Arctic.

Nitzschia cf. *N. frustulum* (Kützing) Grunow
N = 3

Aquatic, in lakes, in attached and planktonic forms; alkaliphilic, halophilic. Cosmopolitan, tolerates pollution and brackish water. Epiphytic and epilithic (O'Quinn and Sullivan 1983:Table 1). Optimum salinity 9.8 g/l (Cumming and Smol 1993). Benthic, oligohalobous (Zalat 2003). Optimum salinity 16.52 g/l (range, 0.35-620.29) in lakes in British Columbia, Saskatchewan, and North Dakota (Wilson, Cumming and Smol 1996:Table 4), where it is abundant and has one of the highest salt tolerances of any of the species represented. Reported from peat bogs in Tierra del Fuego (pH, 6.6-6.8; Mataloni 1999:Tables 1, 2). Has also been found in hot springs in Kenya at 41-46° C (107-115° F) and pH of 8.95-9.58 (Mpawenayo and Mathooko 2004:Table 1, 2) and with optimum pH 7.58 ± 1.05, optimum temperature 30.08 ± 8.30° C (86.1° F) elsewhere in Kenya wetlands (Owen *et al*. 2004:Table 2); pH near 8.6 according to Gasse and Tekaia (1983:Table 6). Found on submerged macrophytes in ponds in Oklahoma (Troeger 1978:Table 2). Occurs abundantly at Lubbock Lake (Winsborough 1995:Table 33). *Nitzschia frustulum* was found in the Guadalupe River in sampling 1955-1982, usually in low abundance with no seasonal pattern (Academy of Natural Sciences of Philadelphia 1991:VII-25). This species was present in 23% of the US rivers evaluated by Potapova and Charles (2002:Table 2).

Nitzschia palea (Kützing) W. Smith
N = 2

Aquatic, in lakes and ponds. Resistant to exposure and desiccation (Evans 1958:161-162). Epiphytic and epilithic (O'Quinn and Sullivan 1983:Table 1). Found in fired clay nodules from sites in Milam County (Winsborough 2001:Table H-2). Found in the Guadalupe River in sampling 1954-1982, usually in low abundance with no seasonal

pattern (Academy of Natural Sciences of Philadelphia 1991:VII-26). This species was present in 32% of the US rivers evaluated by Potapova and Charles (2002:Table 2). Bigler, Hall and Renberg (2000:Table 3) list optimum pH as 6.61 and optimum temperature as 12.5° C (54.5° F) for lakes in northern Sweden. Optimum pH is 8.45 in German lakes and rivers (Schönfelder *et al*. 2002). Antoniades, Douglas and Smol (2005:Table 3) list optimum pH of 7.8 and optimum dissolved organic carbon content of 2.92 mg/l for lakes and ponds in the Canadian Arctic. Also found on submerged rocks and sediment in Canadian Arctic lakes and ponds (Lim, Kwan and Douglas 2001:Table 1). Reported as a soil diatom by Starks and Shubert (1982:Table 2). Reported from peat bogs in Tierra del Fuego (pH, 6.8; Mataloni 1999:Tables 1, 2). Has also been found in hot springs in Kenya at 41-46° C (107-115° F) and pH of 8.95-9.58 (Mpawenayo and Mathooko 2004:Table 1, 2); pH 7.0-7.9 in East Africa (Gasse and Tekaia 1983:Table 6).

Nitzschia tropica Hustedt (Fig. 7.10)
N = 4

Aquatic, cosmopolitan, abundant in saline water (optimum 9.8 g/l); periphytic, planktonic, or benthic; pH near 8.6. Found in large, deep lakes; indifferent to organic pollution. Only occurrence in the bench is four diatom cells from N110 E102 (92.80-92.75 m). Occurs abundantly at the Gibson site (Winsborough 1995:Table 33).

Nitzschia sp.
N = 6 not identifiable to species

Aquatic, in lakes, ponds and streams.

Pinnularia appendiculata (Agardh) Cleve (Fig. 7.9)
N = 17

Aquatic, in marsh and temporary pool habitats, wet walls; epipelic, alkaliphilic. Cosmopolitan, acidophilous (pH 5.0-6.9; Hodgson, Vyverman and Tyler 1997; Gasse and Tekaia 1983:Table 6). Widely distributed in freshwater periphyton but sometimes aerophilous (Ehrlich 1995). Occurs in masses; prefers saline, mineralized waters (Krammer 2000). Optimum salinity 1.94 g/l (range, 0.06-60.81) in lakes in British Columbia, Saskatchewan, and North Dakota (Wilson, Cumming and Smol 1996:Table 4). Reported from peat bogs in Tierra del Fuego (pH, 4.3-6.8; Mataloni 1999:Tables 1, 2). Optimum pH is 7.51 in German lakes and rivers (Schönfelder *et al*. 2002). Occurs in epipelic and epilithic form in circumneutral lake water at 6-15° C (42.9-59° F; Sahin and Akar 2005). Reported from sandstone cliff walls in Ohio (Casamatta *et al*. 2002:Table2).

Pinnularia borealis Ehrenberg (Figs.7.7, 7.18)
N = 1387

Both aerophilic and aquatic, found in soil and mud, lakes, ponds and rivers; attaches to plants and rocks. In aquatic habitats, a cool water form usually found in water between 0° and 15° C, optimum pH less than 6 (range, 4.0-8.0), current indifferent; occurs in sulfate and chloride-rich saline waters; characteristic of waters with high concentrations of inorganic nutrients. Prefers cool water of low mineral content, often in rivers but also in ponds (Patrick and Reimer 1966); epipelic, aerophilic (Campeau, Pienitz and Héquette 1999). Reported from peat bogs in Tierra del Fuego (pH, 4.3-6.8; Mataloni 1999:Tables 1, 2). Has also been found in hot springs in Kenya at 41-46° C (107-115° F) and pH of 8.95-9.58 (Mpawenayo and Mathooko 2004:Table 1, 2). Listed as benthic and "aerophytic" by Caljon and Cocquyt (1992:154). The second most abundant diatom in the bench sediments. Absent or rare at southern Plains sites discussed by Winsborough

(1995:Table 33). Antoniades, Douglas and Smol (2005:Table 3) list optimum pH of 6.7 and optimum dissolved organic carbon content of 1.80 mg/l for lakes and ponds in the Canadian Arctic. Optimum pH is 6.37 in German lakes and rivers (Schönfelder *et al*. 2002); near 7.0 in East Africa (Gasse and Tekaia 1983:Table 6). Found as soil diatom in Greenland (van Kerckvoorde *et al*. 2000:Appendix 1). Occurs in epipelic and epilithic form in circumneutral lake water at 6-15° C (42.9-59° F; Sahin and Akar 2005). Found occasionally on sandstone cliffs wet by seepage in Kentucky (Camburn 1982:Table 1) and Ohio (Casamatta *et al*. 2002:Table 2).

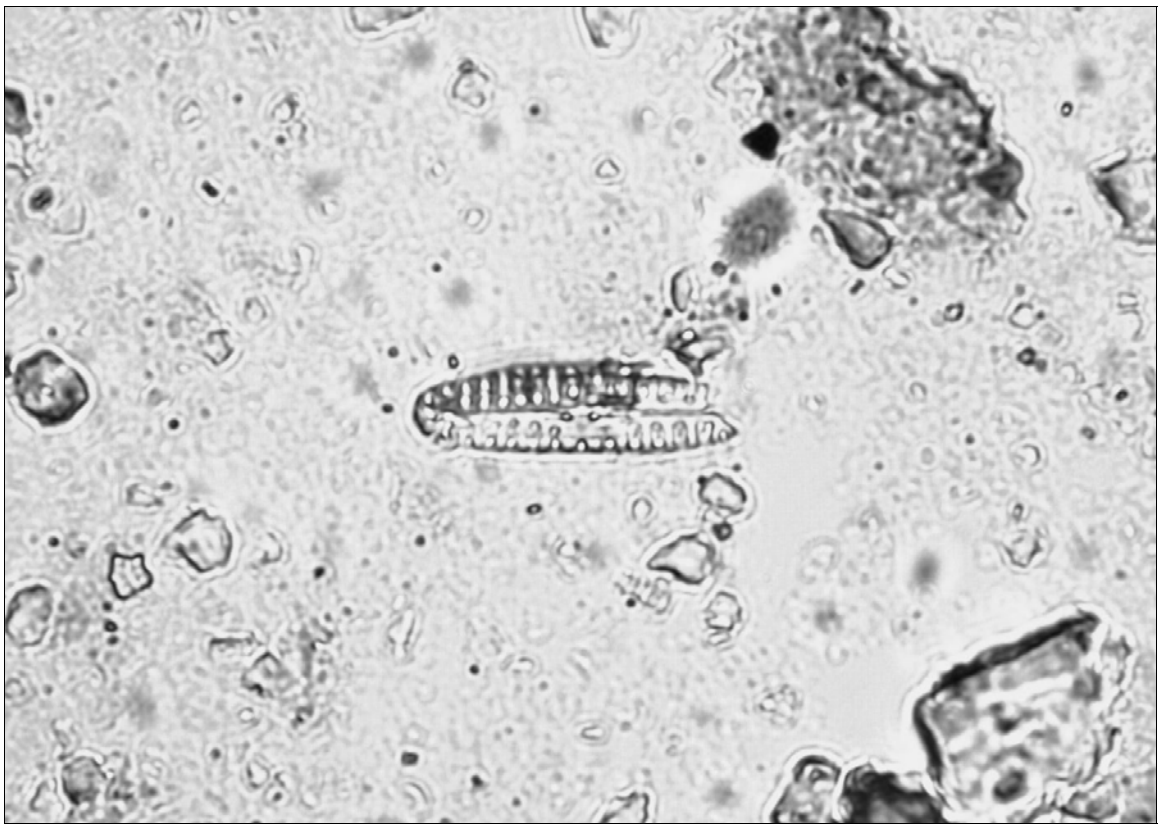

Figure 7.18. *Pinnularia borealis*. Diatom sample 28; N110 E102 (91.60-91.55 m), lowest sample in stratum 1, 50X lens

Pinnularia braunii (Grunow) Cleve
N = 1

Aquatic, in lakes and ponds. In Costa Rica, the variety *P. b*. var. *amphiceplala* prefers lake waters with low alkalinity, hardness, calcium and magnesium (Haberyan, Horn and Cumming 1997:271). Found occasionally on sandstone cliffs wet by seepage in Kentucky (Camburn 1982:Table 1). The single example of this species comes from sample 2 in N109 E103; there are none from the N110 E102 sample column.

Pinnularia gibba Ehrenberg (Fig. 7.10)
N = 4

Aquatic, in springs and streams. Bigler, Hall and Renberg (2000:Table 3) list optimum pH as 6.82 and optimum temperature as 12.9° C (55.3° F) for lakes in northern Sweden. Occurs in epipelic and epilithic form in circumneutral lake water at 6-15° C (42.9-59° F; Sahin and Akar 2005).

Pinnularia microstauron (Ehrenberg) Cleve
N = 2

Aquatic, in marshes, ponds and streams. May be common in acid waters; pH of 5.0-6.9 (Gasse and Tekaia 1983:Table 6). Cosmopolitan, fresh-brackish to fresh water, benthic, epiphytic (Hodgson, Vyverman and Tyler 1997); shallow lakes, bogs, rivers, aerophilous, tolerates wide range of water chemistry and temperature (Gasse 1986). Optimum salinity 0.3 g/l (Cumming and Smol 1993). Optimum salinity 0.86 g/l (range, 0.02-48.64) in lakes in British Columbia, Saskatchewan, and North Dakota (Wilson, Cumming and Smol 1996:Table 4). This species was characteristic of Carolina bays (ponds) with a relatively short hydroperiod studied by Gaiser, Philippi and Taylor (1998:Table 3). Bigler, Hall and Renberg (2000:Table 3) list optimum pH as 6.58 and optimum temperature as 12.1-12.5° C (53.8-54.5° F) for lakes in northern Sweden. Optimum pH is 6.37 in German lakes and

rivers (Schönfelder et al. 2002). Reported from peat bogs in Tierra del Fuego (pH, 4.3-6.8; Mataloni 1999:Tables 1, 2). Found as soil diatom (Hayek and Hulbary 1956; van Kerckvoorde *et al*. 2000:Appendix 1). Reported from sandstone cliffs in Ohio (Casamatta et al. 2002:Table2). In plankton samples from pond, sediment in wet meadows, and on stream rocks in Utah (St. Clair and Rushforth 1977:376). Has also been found in hot springs in Kenya at 41-46° C (107-115° F) and pH of 8.95-9.58 (Mpawenayo and Mathooko 2004:Table 1, 2). Found at 33-45° C in Yellowstone hot springs (Stockner 1967:Table 1).

Pinnularia obscura Krasske
N = 3

Both aerophilic and aquatic, found in moss and ponds. Has been found as a soil diatom (Bérard *et al*. 2004:Table 3). This species was characteristic of Carolina bays (ponds) with a relatively short hydroperiod studied by Gaiser, Philippi and Taylor (1998:Table 3), suggesting it is adapted to desiccation. Antoniades, Douglas and Smol (2005:Table 3) list optimum pH of 7.9 and optimum dissolved organic carbon content of 2.06 mg/l for lakes and ponds in the Canadian Arctic. Gasse and Tekaia (1983:Table 6) list pH of 5.0-5.9.

Pinnularia subcapitata Gregory (Fig. 7.10)
N = 4

Both aerophilic and aquatic, found in soil, marshes and ponds. This species was characteristic of Carolina bays (ponds) with a short hydroperiod studied by Gaiser, Philippi and Taylor (1998:Table 3), suggesting it is adapted to desiccation. Reported from sandstone cliff walls in Ohio (Casamatta *et al*. 2002:Table2). Optimum pH is 4.68 in German lakes and rivers (Schönfelder *et al*. 2002). Has also been found in hot springs in Kenya at 41-46° C (107-115° F) and pH of 8.95-9.58 (Mpawenayo and Mathooko 2004:Table 1, 2). Listed as “aerophytic” and benthic by Caljon and Cocquyt (1992:154).

Pinnularia viridis (Nitzsch) Ehrenberg (Fig. 7.9)
N = 15

Both aerophilic and aquatic; in aquatic habitats benthic, epiphytic, found in water with moderate electrolytes. Aerophilic in damp habitats; on bryophyte mat on wet sandstone (Lowe and Collins 1973:Table 1). Found occasionally on sandstone cliffs wet by seepage in Kentucky (Camburn 1982:Table 1) and Ohio (Casamatta *et al*. 2002:Table2). Found in cold and warm water (9.8-28.4° C, pH 7.35-7.95) in a calcareous Iowa fen (Shobe, Stoermer and Dodd 1963:Table 1, 2). On rocks from streams in Québec (Wunsam, Cattaneo and Bourassa 2002:Table 4). This species was characteristic of Carolina bays (ponds) with a relatively short hydroperiod studied by Gaiser, Philippi and Taylor (1998:Table 3). Capable of surviving severe but not prolonged drought; found on exposed mud and litter surfaces, but more common in water (Evans 1958:161). Reported from peat bogs in Tierra del Fuego (pH, 4.4-6.8; Mataloni 1999:Tables 1, 2). Occurs abundantly at the Flagg site (Winsborough 1995:Table 33). Bigler, Hall and Renberg (2000:Table 3) list optimum temperature as 10.8° C (51.5° F) for lakes in northern Sweden. Optimum pH is 6.68 in German lakes and rivers (Schönfelder *et al*. 2002). Abundant in shallow pond sediments from Locality 8 at Lambs Creek, Leon County (Winsborough 1991:Table 88).

Pinnularia sp. (Fig. 7.9)
N = 20 not identifiable to species

Pseudostaurosira brevistriata (Grunow) Williams and Round (= *Fragilaria brevistriata*)
N = 12

Aquatic, in lakes, streams, and ponds; early colonizer of new lakes; periphytic, benthic, alkaliphilic. Periphytic in shallow lakes, ponds, rivers, swamps; alkaliphilous (Ehrlich 1995). Found in running, well-oxygenated water (Gasse 1986). Optimum salinity 0.2 g/l

(Cumming and Smol 1993); optimal water depth 6.4±0.8 m (Campeau, Pienitz and Héquette 1999); salt and current indifferent, alkaliphilous (Haworth 1977). Has also been found (as *Fragilaria brevistriata*) in hot springs in Kenya at 41-46° C (107-115° F) and pH of 8.95-9.58 (Mpawenayo and Mathooko 2004:Table 1, 2). Occurs abundantly at Lubbock Lake and Mustang Springs (Winsborough 1995:Table 33). Rare in the Guadalupe River (Academy of Natural Sciences of Philadelphia 1991:VII-15).

Rhopalodia gibba (Ehrenberg) O. Müller (Figs. 7.7, 7.19)
N = 94

Aquatic, in lakes, playas and marshes; epiphytic, in high conductivity water. Found on submerged macrophytes in ponds in Oklahoma (Troeger 1978:Table 2). Epiphytic on *Phragmites* stems (Müller 1999:Table 1). Found on bryophyte mat on wet sandstone (Lowe and Collins 1973:Table 1). Found in cold and warm water (9.8-28.4° C, pH 7.35-7.95) in a calcareous Iowa fen (Shobe, Stoermer and Dodd 1963:Table 1, 2). On rocks from streams in Québec (Wunsam, Cattaneo and Bourassa 2002:Table 4). Found in ponds and wet meadows and in plankton samples of stream in Utah (St. Clair and Rushforth 1977:384). Cosmopolitan, brackish-fresh to fresh-brackish water (Hodgson, Vyverman and Tyler 1997); epiphytic in swamps, lakes and rivers; occurs in salt concentrations less than 0.5 g/l and in alkaline water (Gasse 1986); optimum salinity 0.7 g/l (Cumming and Smol 1993); epipelic, epilithic (Czarnecki 1979); attached (Zalat 2003). Optimum salinity 0.87 g/l (range, 0.18-4.14) in lakes in British Columbia, Saskatchewan, and North Dakota (Wilson, Cumming and Smol 1996:Table 4). Optimum pH 7.14 ± 0.63, optimum temperature 28.90 ± 7.77° C (84° F) in Kenya wetlands (Owen *et al*. 2004:Table 2); pH near 8.6 according to Gasse and Tekaia (1983:Table 6). Listed as "aerophytic, planktonic, benthic" by Caljon and Cocquyt (1992:154). According to Lowe (2003:681), "This genus

is found in hard-water nitrogen-poor benthic habitats like those characteristic of *Epithemia*." Abundant at most sites discussed by Winsborough (1995:Table 33).

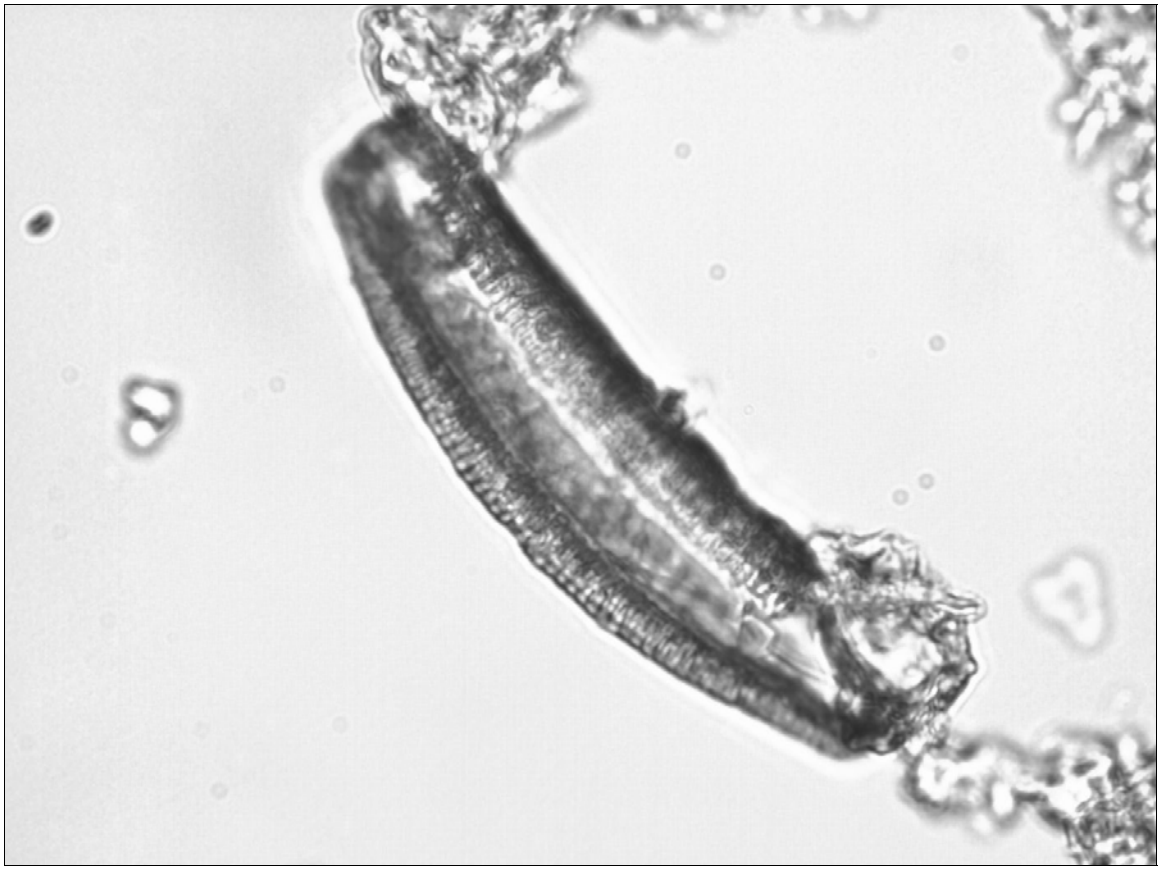

Figure 7.19. *Rhopalodia gibba*. Diatom sample 19; N110 E102 (92.05-92.00 m), stratum 2A, 50X lens.

Rhopalodia gibberula (Ehrenberg) O. Müller (Fig. 7.11)
N = 5

Aquatic, in lakes, playas and marshes; epiphytic, halophilic. This salt-tolerant species occurs abundantly at most of the sites discussed by Winsborough (1995:Table 33), where it is considered to be indicative of brackish water conditions. Optimum salinity 2.36 g/l (range, 0.21-26.85) in lakes in British Columbia, Saskatchewan, and North Dakota

(Wilson, Cumming and Smol 1996:Table 4). Epiphytic and epilithic (O'Quinn and Sullivan 1983:Table 1). Optimum pH 7.59 ± 0.74, optimum temperature 33.31 ± 9.58° C (92° F) in Kenya hot springs and wetlands (Owen *et al*. 2004:Table 2); pH 8.6-10.9 according to Gasse and Tekaia (1983:Table 6).. The variety *vanheurckii* O. Müller is found occasionally on sandstone cliffs wet by seepage in Kentucky (Camburn 1982:Table 1). Found in warm water (28.4° C, pH 7.95) in a calcareous Iowa fen (Shobe, Stoermer and Dodd 1963:Table 1, 2). Found in ponds, stream, and wet meadows, epilithic and in plankton samples, in Utah (St. Clair and Rushforth 1977:384) and dry lakebottom sediment in Nevada (VanLandingham 1966:Table 1, 235).

Sellaphora pupula (Kützing) D. G. Mann (= *Navicula pupula*)
N = 2

Aquatic, in ponds; periphytic, alkaliphilic, halophilic. Cosmopolitan in brackish-fresh waters, benthic (Hodgson, Vyverman and Tyler 1997); epipelic in ponds and lakes; tolerates small amounts of salt, pH-indifferent (Ehrlich 1995); found in hot springs, rivers, peat bogs, lakes in benthic or epiphytic habit, tolerates wide range of salt and temperature (Gasse 1986); epipelic and epilithic (Czarnecki 1979); salt, pH and current – indifferent (Haworth 1997). Optimum salinity 0.3 g/l (Cumming and Smol 1993). On rocks from streams in Québec (Wunsam, Cattaneo and Bourassa 2002:Table 4). Has also been found (as *Navicula pupula*) in hot springs in Kenya at 41-46° C (107-115° F) and pH of 8.95-9.58 (Mpawenayo and Mathooko 2004:Table 1, 2). Optimum pH 6.84 ± 0.24, optimum temperature 29.11 ± 4.70° C (84.4° F) in Kenya wetlands (Owen *et al*. 2004:Table 2). Reported from sandstone cliffs in Ohio (Casamatta *et al*. 2002:Table2).

Stauroneis obtusa Lagerstedt (Fig. 7.11)
N = 9

Aquatic, in flowing water; alkaliphilic. Has been found as a soil diatom (Bérard *et al*. 2004:Table 3). Listed as "aerophytic, benthic" by Caljon and Cocquyt (1992:154).

Stauroseira construens Ehrenberg (= *Fragilaria brevistriata*)
N = 1

Both aquatic and aerophilic. In aquatic habitats, occurs in littoral zone or as benthic and planktonic forms in turbid water; an opportunistic species. Cosmopolitan, tychoplanktonic and benthic, in freshwater lakes receiving some brackish water (Hodgson, Vyverman and Tyler 1997); indicator of well-oxygenated waters (Ehrlich 1995). Prefers shallow areas of lakes, swamps, rivers and springs, prefers fresh water of medium pH and alkalinity but tolerates wide range of chemical conditions (Gasse 1986); pH near 8.6 (Gasse and Tekaia 1983); optimum salinity 0.1 g/l (Cumming and Smol 1993).

Surirella sp.
N = 1 not identifiable to species

Aquatic, in bottom mud of lakes and ponds. The genus is reported both from the Guadalupe River in sampling 1955-1982, usually in low abundance (Academy of Natural Sciences of Philadelphia 1991:VII-27 to VII-28) and Coleto Creek (Espey, Huston & Associates 1976:Table 4). The genus (species not identified) was characteristic of Carolina bays (ponds) with a relatively long hydroperiod studied by Gaiser, Philippi and Taylor (1998:Table 3).

SPECIES ACCOUNTS: DIATOMS FROM THE LISSIE TERRACE

The single sample (number 42) from the Lissie terrace exposure that produced diatoms contains a few of the same species found in the bench deposits, except for two unique species not found in any of the bench samples:

Opephora martyi [= *Fragilaria martyi* (Héribaud) Lange-Bertalot]
N = 5

Aquatic, prefers standing water, attaches to plants in lakes and rivers; alkaliphilous to alkalibiontic; optimum pH 7.8-8.2 (range, 6.4-9.0), in eutrophic to mesotrophic waters, indifferent to small amounts of salt. Reported as benthic and euryhaline in Lake Tanganyika lakebottom sediments (Caljon and Cocquyt 1992:135-156). Occurs rarely in dry lake bottoms in Nevada (VanLandingham 1966:Table 1).

Staurosirella pinnata (Ehrenberg) Williams and Round (= *Fragilaria pinnata*)
N = 17

Aquatic and aerophilous, found in lakes, ponds, playas and dry lakes; attached to plants, rock and wood; also found in mud. Thrives optimally only in cool, well-oxygenated water; characteristic of standing water, but indifferent to current. Alkaliphilous; optimum pH 7.6-7.8 (range, 5.7-9.0). Gasse and Tekaia (1983:Table 6, as *Fragilaria pinnata*) list pH as 7.0-7.9 for East Africa. Prefers eutrophic water; indifferent to small amounts of salt. Reported (as *Fragilaria pinnata*) from dry lakebottom sediment in Nevada (VanLandingham 1966:Table 1).

FRESHWATER SPONGE SPICULES

Freshwater sponges are collagen supported by a reticulate skeleton of microscopic, needlelike spicules made of opal (hydrated silica; Pennak 1989:95). These can be preserved in alluvial sediments when the sponge tissue disintegrates, and megascleres (the largest type of spicule) are readily visible under magnification. Because they are made of amorphous silica, they will extinguish under polarized light. Sponge spicules are most often recovered from lake sediments (Frost 2001; Wilkins *et al*. 1991), but can also be present in terrestrial soils (Clarke 2003:180-181; Jones and Beavers 1963). Unfortunately, megasclere morphology is not very diagnostic of species (Harrison and Warner 1986:116). The smaller types of spicules (microscleres and gemmoscleres) are more distinctive but require more magnification and have not been observed in the Berger Bluff dust samples.

Microscopic spicules from freshwater sponges are apparently scattered throughout the bench deposits. They were visible in the diatom sample slides and on dust fractions extracted from raw sediment samples (coating glass microscope slides), and they appear in the sediment thin sections from strata 1 and 2A discussed in Chapter 4 (slides 5, 6, and 7; Fig. 4.92, *top*). Megascleres can be seen at magnifications of about 200-400X and above. No attempt to tally or quantify these spicules was made, but from qualitative observations made by Barbara Winsborough, it appears that spicules are most abundant in the lower part of the bench deposits, below 92.00 m, are moderately abundant in the middle of the deposits, and become scarce above 92.65 m (Table 7.1). The uppermost diatom samples apparently contain only a few broken spicules. In scanning duplicate slides, I found very few spicules above stratum 2A. Although unverified quantitatively, it

seems likely that the density of spicules probably parallels the upwardly-declining density of diatoms seen on the slides (Fig. 7.4). The single diatom sample from stratum 2E (sample 44 at 93.45-93.40 m) lacks spicules entirely and has very few diatoms.

Winsborough did not find any visible sponge spicules in diatom samples from stratum 4 (sample 39, N97 E96, 97.75 m) and stratum 5 (sample 29, N97 E96, 99.75 m) in the blufftop excavation, and scanned dust samples from the 99.00 m and 99.75 m levels also lacked spicules. In scanning a duplicate slide (number 29) from the 99.00 m level, I found only one or two fragments of spicules (Fig. 7.20). The evidence seems to suggest that conditions in Coleto Creek were favorable for sponge growth during the early history of the bench deposits, became somewhat less favorable during the middle part of the bench section, and became unfavorable as the bench deposits stopped accumulating. Conditions may have been unfavorable throughout the accumulation of the upper deposits in the Holocene, although Robinson (1979) reports sponge spicules from all of the samples examined at 41 GD 21, located nearby on Sulphur Creek. Presumably, the upward decline in density and eventual disappearance of the spicules is controlled by the size of the sponge populations in Coleto Creek, and not by taphonomic decay or by varying rates of sediment dilution. Freshwater sponges are not reported in the pre-inundation assessment done by Murray, Jinnette and Moseley (1976).

In Lissie stratigraphic section 2, dust fractions from all four sediment samples were scanned, but no spicules were seen. In Lissie stratigraphic section 1, no spicules were seen in sample 1-1, occasional spicules were seen in sample 1-2, and very well-preserved, complete or nearly complete spicules were seen in sample 1-3. In sample 1-4, only one possible spicule was seen.

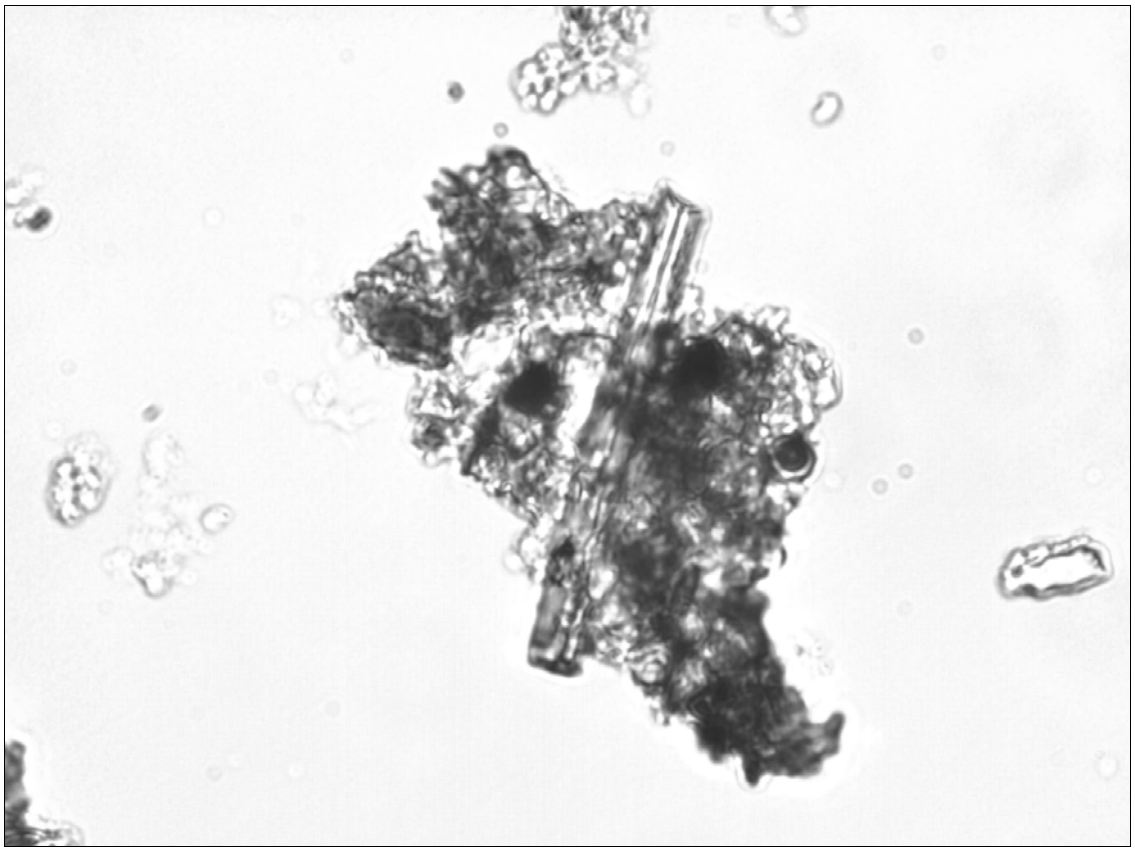

Figure 7.20. Freshwater Sponge Spicule Fragment From Stratum 5. Sample 29 from upper deposits, N97 E96 (99.75 m). This small medial megasclere fragment was one of only one or two found in scanning of the slide. The sample comes from the upper part of stratum 5, about 25 cm below the ground surface.

The species of sponge present in the bench sediments is unidentified, but all of the spicules seen in the dust fractions on microscope slides seem to be of the same type, relatively slender, arched, smooth megascleres with a central axial filament of collagen around which the spicule forms (Figs. 7.21, 7.22). Many of the spicules from the bench sediments are broken central or distal fragments, but complete or nearly complete megascleres (Figs. 7.23, 7.24) resemble published illustrations of *Spongilla lacustris*, the most widespread and common freshwater sponge in North America (Frost 1991:Figs. 4.6,

4.7). *Spongilla lacustris* has megascleres about 200-350 μm (0.2-0.35 mm) long (Frost 1991:120). There are several other species that can have smooth, slightly curved megascleres, however (for example, *Eunapius fragilis*, *Heteromeyenia baileyi*), and Poirrier (1972) reports at least nine species of freshwater sponges are present in Texas. According to Pennak (1989:101), "it is common to find three different species in the same lake, less common to find four, and rare to find five or six," so it is possible that more than one species might be present in the bench deposits.

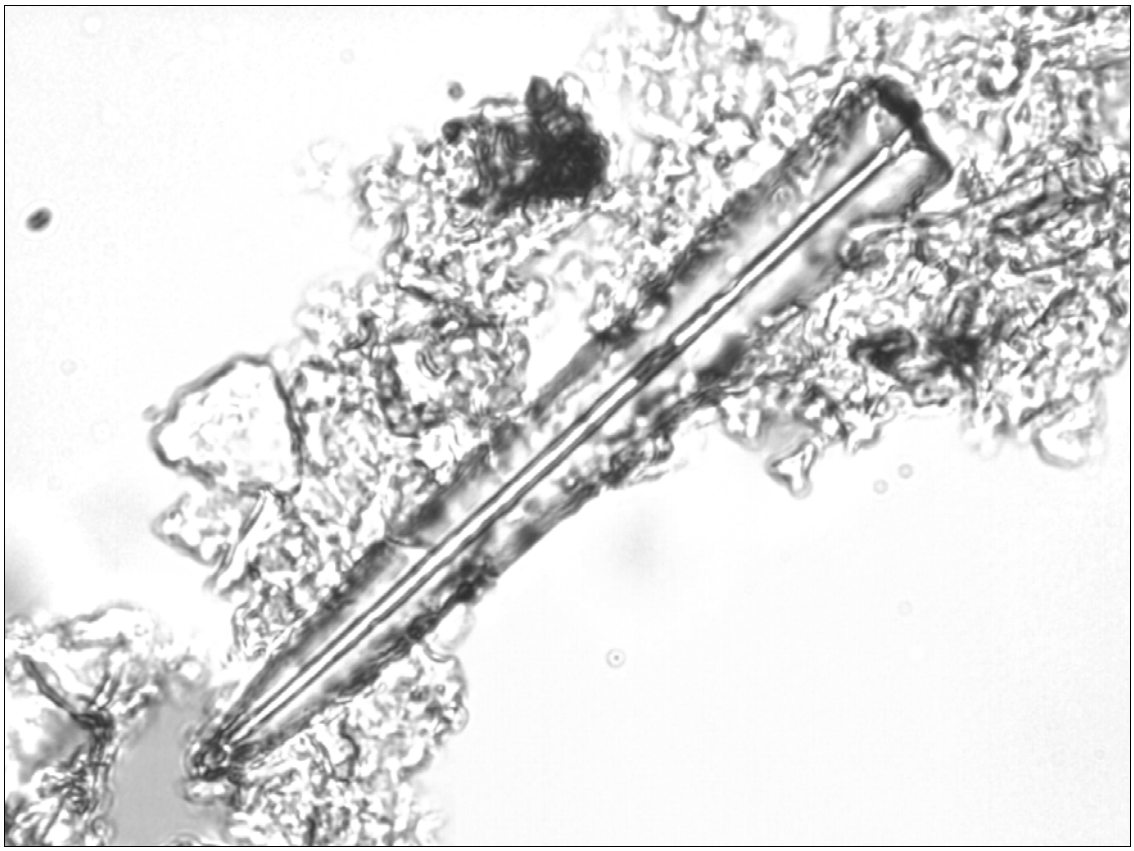

Figure 7.21. Freshwater Sponge Spicule From Stratum 2A. N110 E102 (92.05-92.00 m), sample 19, 50X lens. Distal end of megasclere.

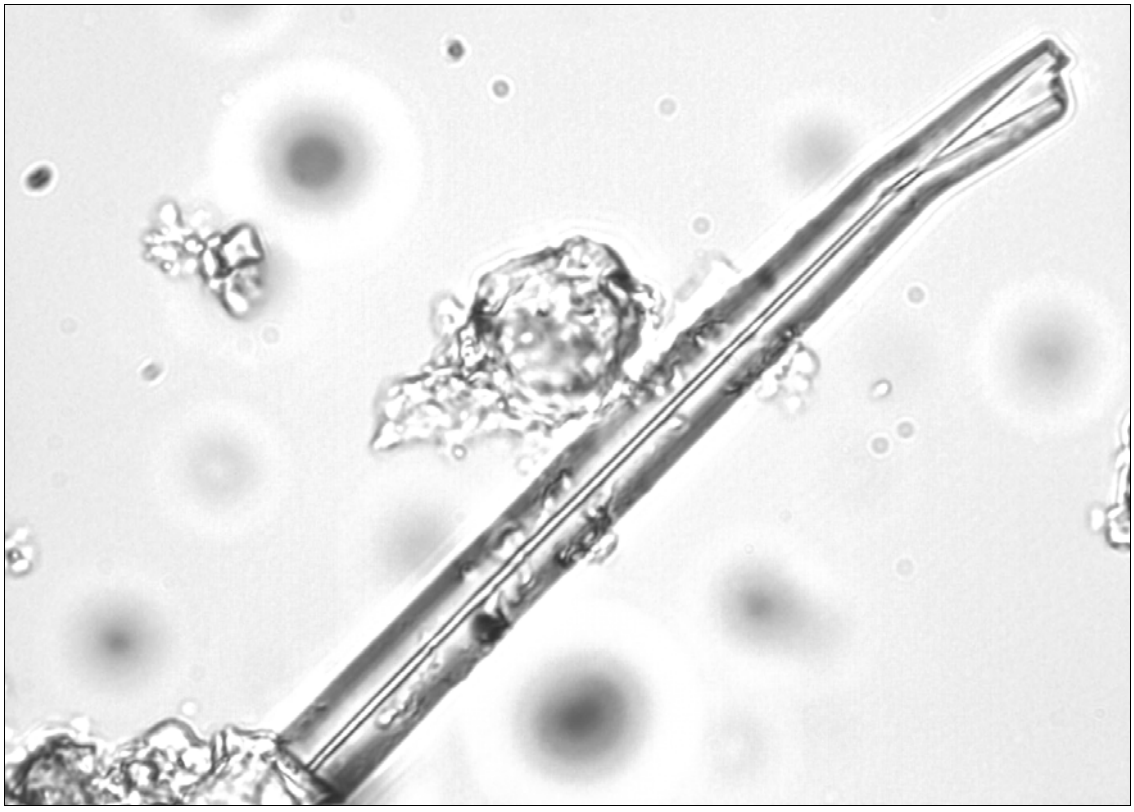

Figure 7.22. Freshwater Sponge Spicule From Stratum 1. N110 E102 (91.85-91.80 m), sample 23, 50X lens. Medial fragment of megasclere with bending fracture.

Presumably, the spicules are the remains of sponges that grew in Coleto Creek during the Younger Dryas and early Holocene, decomposing and shedding spicules into bottom mud that was later swept up and deposited as overbank sediment on the floodplain. Because sponges are often found encrusting submerged roots or deadwood, it is also possible some sponge tissue could be carried onsite attached to floating wood during overbank floods. Because the spicules seen in the Lissie samples are the same type as those seen in the bench, and because many of the bench specimens are broken, the possibility that the Lissie terrace contributed some spicules cannot entirely be ruled out. But the limited

stratigraphic occurrence of spicules in the Lissie terrace suggests it was not a major contributor of spicules to the bench sediments. The apparent (though quantitatively undemonstrated) co-occurrence of diatoms and sponge spicules suggest both derive from the same source.

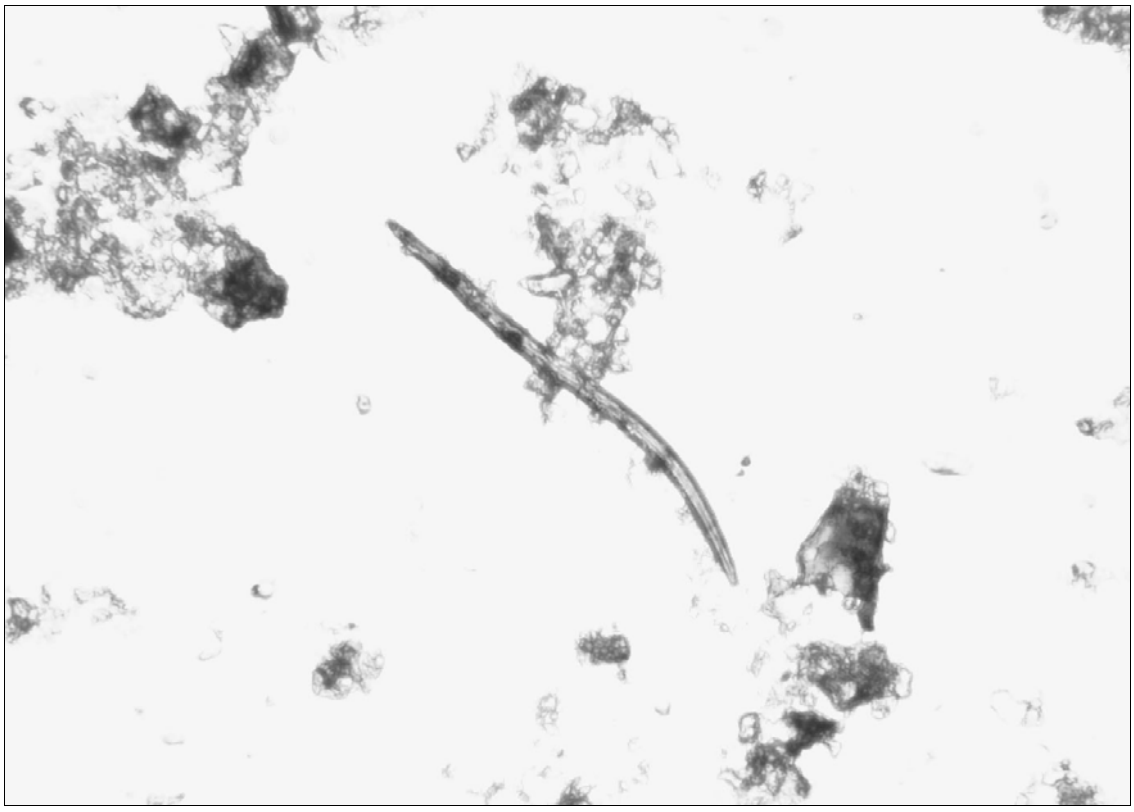

Figure 7.23. Complete Sponge Spicule From Stratum 2A. N110 E102 (92.05-92.00 m), sample 19, 10X lens. This is the same slide as Fig. 7.21, but at one-fifth the magnification, showing a complete but unidentified megasclere from the lower part of stratum 2A.

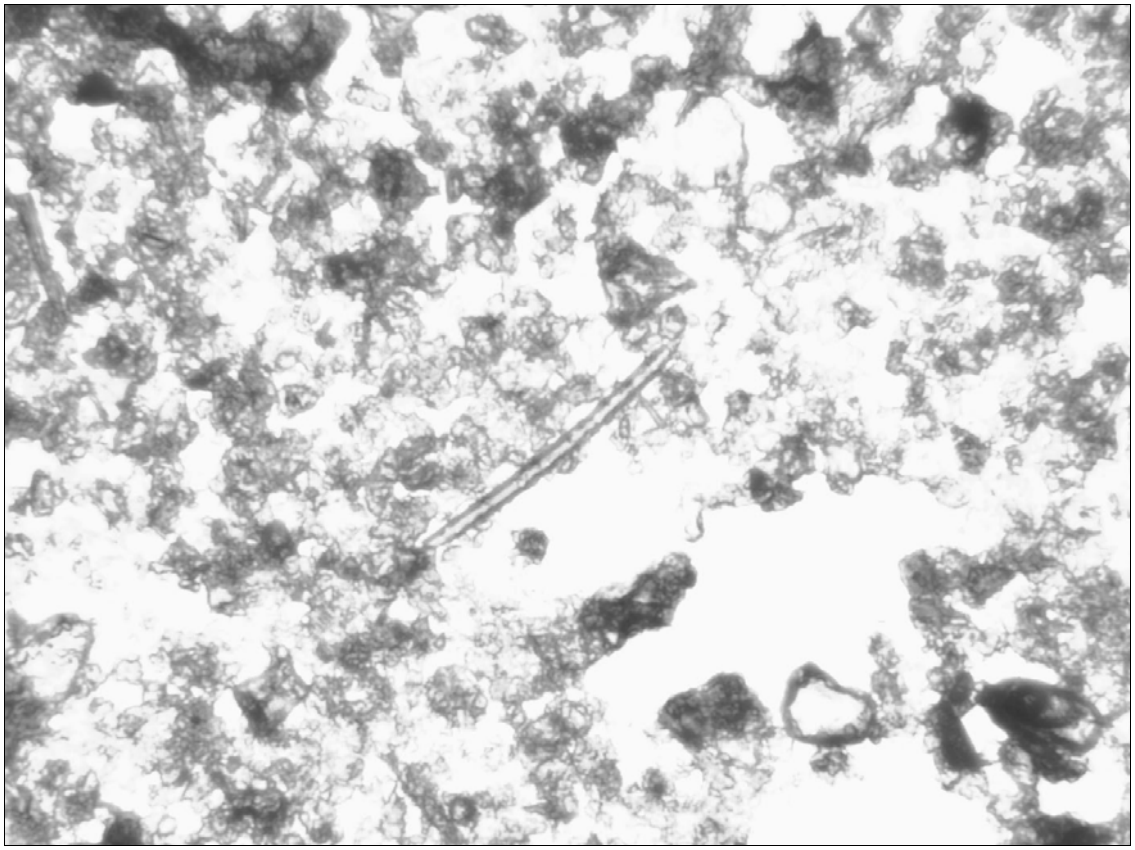

Figure 7.24. Another Complete Sponge Spicule From Stratum 2A. N110 E102 (92.05-92.00 m), sample 19, 10X lens. This is the same sample and magnification as in the previous figure.

Pennak (1989:99) reports that freshwater sponges are most common in water less than 2 m deep, and are rarely found on mud bottoms, in silty or very rapid water. However, *Spongilla lacustris* is known to grow on soft mud bottoms (Frost 1991:107; Frost, de Nagy and Gilbert 1982), and Cheatum and Harris (1953:100) observed that sponges of various species were as abundant in Dallas County in muddy ponds and sluggish streams as in clear water. Turbidity did not seem to be a limiting factor for sponge distribution, although they are phototropic (light-seeking) organisms. Most colonies are found encrusting submerged deadwood, roots, or basal stalks of cattails and sedges. Cheatum and Harris (1953:100) report turbidities of 20-150 ppm; Harrison (1974:51) reports that

Spongilla lacustris tolerates turbidity of 2-200 ppm, Secchi disk visibility of 0.9-7.3 m, and a wide range of temperature (12-37° C) and pH (5.3-9.0). In eastern Canada, the species tolerates water temperature of 4-25° C and pH 4.8-9.0 (Ricciardi and Reiswig 1993:676). Sponges are also susceptible to crawdad predation (Williamson 1979).

Besides sponge spicules, other kinds of biosilica can be seen on the diatom slides. Phytoliths (Figs. 7.25, 7.26) are common but have not been identified or quantified.

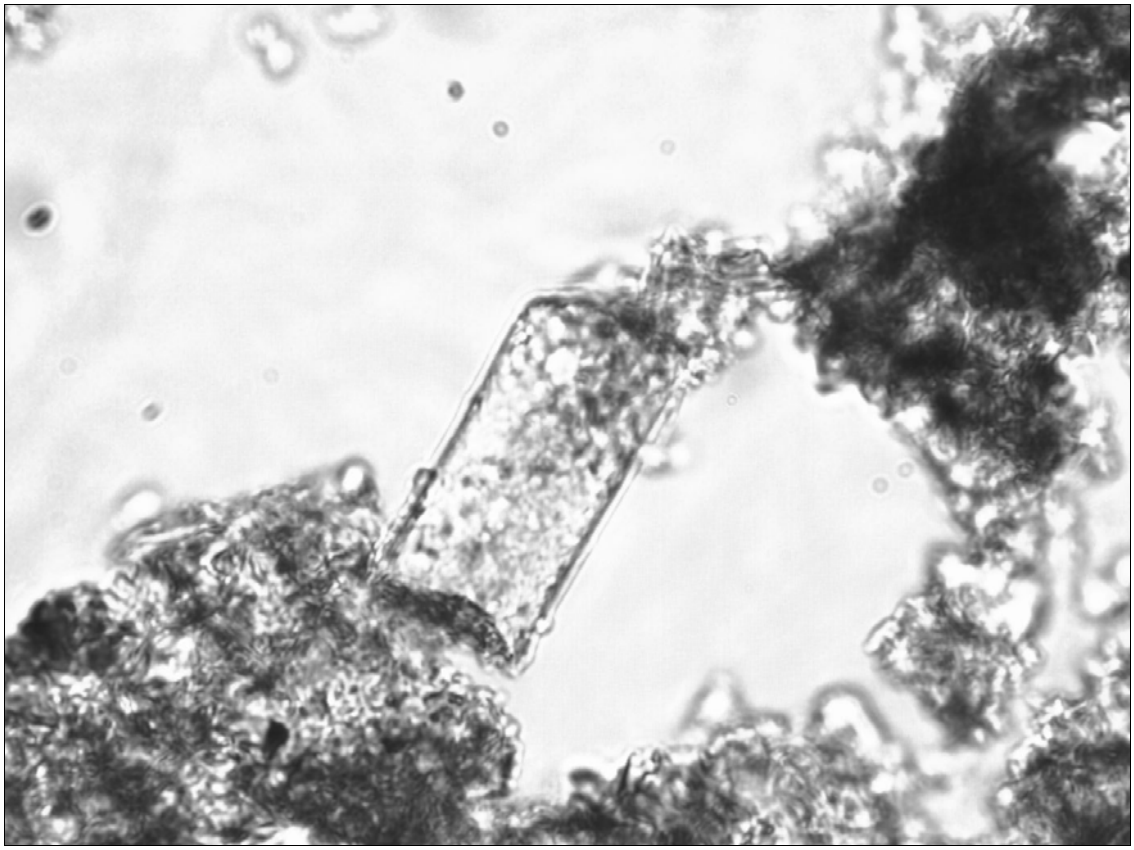

Figure 7.25. Probable Phytolith From Stratum 5. N97 E96 (99.75 m), sample 29, 50X lens. Unidentified phytolith from the upper deposits; same slide as Fig. 7.20.

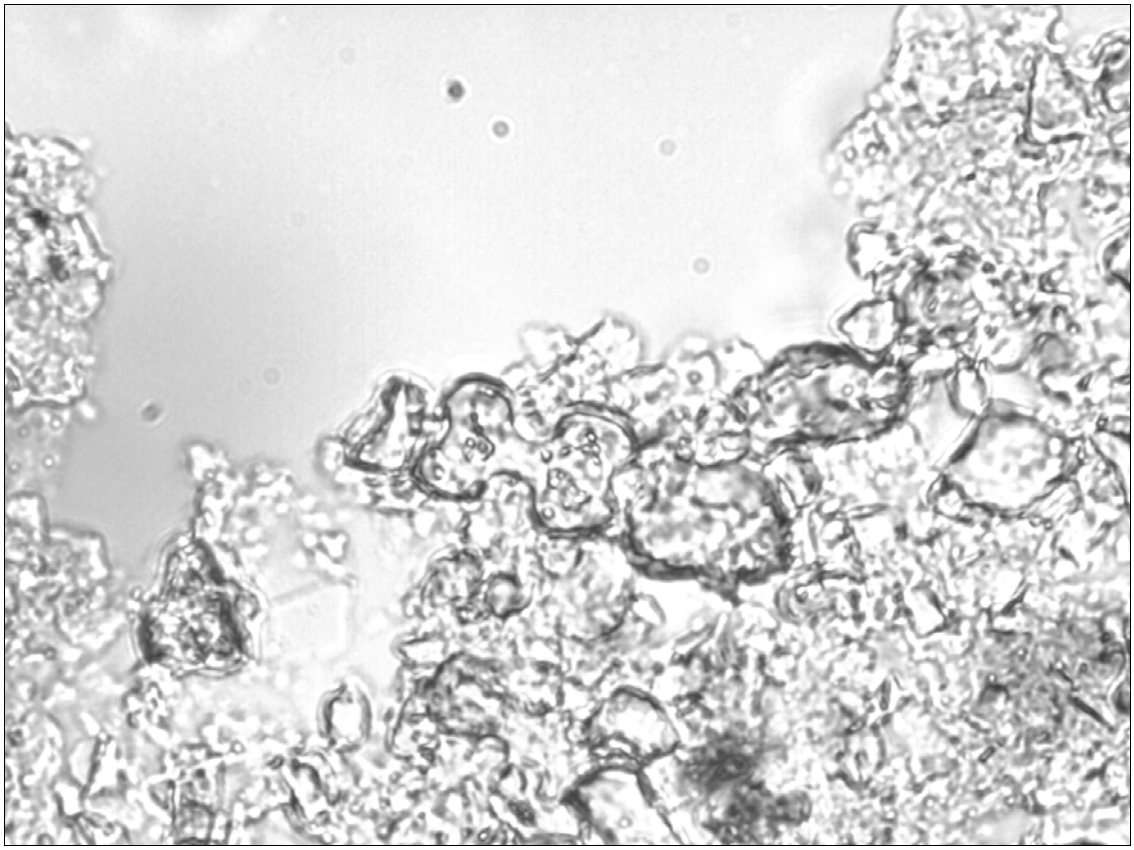

Figure 7.26. Unidentified Phytolith From Stratum 2B. N110 E102 (92.20-92.15 m), sample 16, 50X lens. Dumbbell-shaped phytolith (in exact center of image) from the basal contact of stratum 2B.

SUMMARY AND CONCLUSIONS FOR CHAPTER 7

At least four kinds of biosilica (diatoms, freshwater sponge spicules, chrysophyte cysts, and phytoliths) were found in the bench deposits, but only the diatoms were studied systematically. A single column of samples collected at 5 cm intervals (except near the top of the column) was analyzed, supplemented by three additional samples from N109 E103 and one from stratum 2E. Additional comparative samples from the Lissie terrace and upper deposits were also analyzed.

Although cienega sites like the Gibson (Marks Beach) site may produce over 100 species of diatoms (Winsborough 1995:Table 33), many terrestrial sites in Texas have produced only sparse counts and limited assemblages of diatoms. It is a fairly common occurrence for samples from archeological sites to produce very depauperate assemblages, either from taphonomic decay or because the sediments were not good diatom sinks to begin with. In contrast, the bench deposits at Berger Bluff have produced a fairly abundant and taxonomically diverse diatom assemblage of at least 65 species, mostly from the lower part of the deposits. Figure 7.27 shows how abundances of these species are distributed. The 72 categories (65 species plus some identified only to generic level) are ranked by abundance. Only a few of the most abundant species at the left are labeled.

Diatom species often have global or near-global distributions, and many of the species found in the Berger Bluff bench deposits can also be found today in such exotic locations as Africa, Turkey, Japan, Antarctica, or Greenland. Consequently, biogeography is of no help in understanding the environmental requirements of different species. Many are equally cosmopolitan in terms of physical or chemical variables. For example, *Nitzschia amphibia* is reported from lakes and ponds in the Canadian Arctic, from peat bogs in Tierra del Fuego, and from hot springs in Kenya (as well as from the Guadalupe River). Diatoms are not particularly temperature-sensitive, in any case (Anderson 2000). This frequently wide adaptability makes it difficult to derive environmental interpretations from assemblage composition or to interpret the axes derived from correspondence analysis.

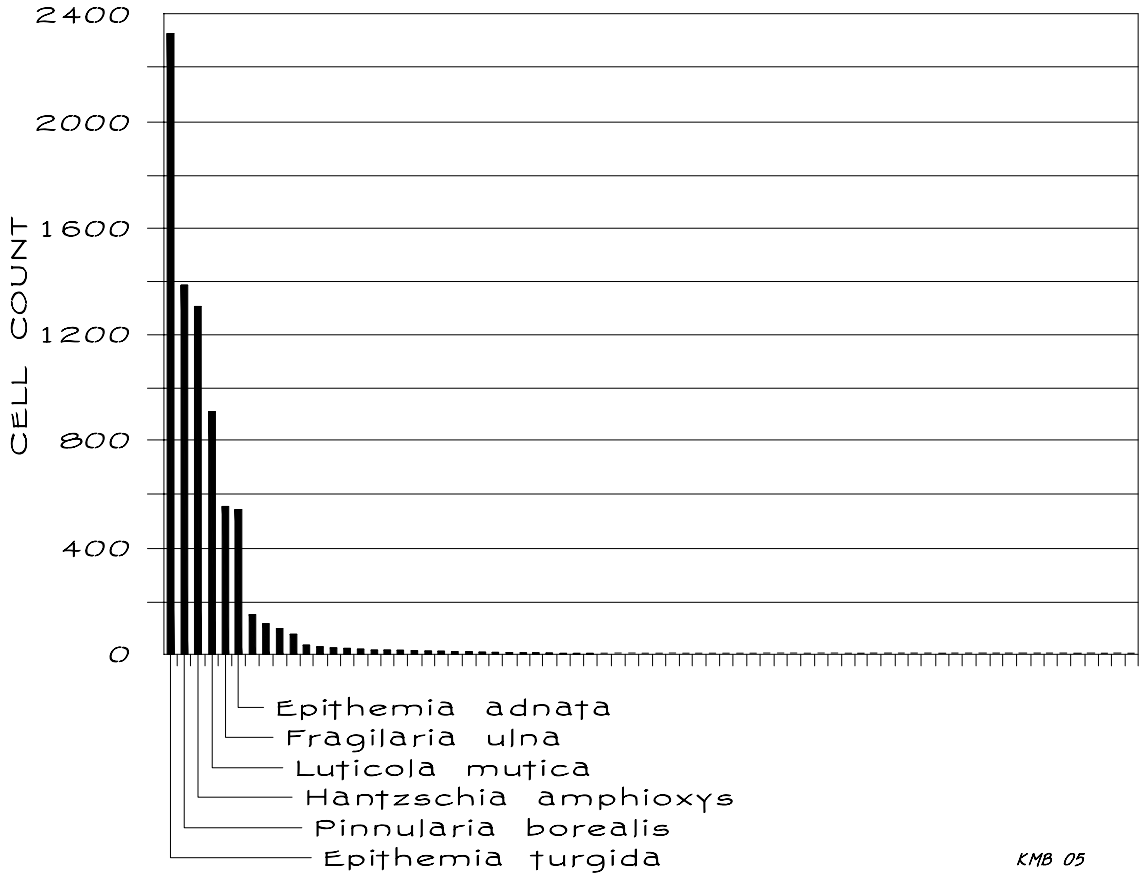

Figure 7.27. Relative Proportions of Diatom Taxa. Summing all counts from the bench deposits, this histogram shows all 72 taxonomic categories ranked by abundance from left to right, but only the most abundant taxa are prominent enough to show at this scale. Only the six most abundant ones are labeled. The purpose of this histogram is to show that, time-averaged over the 2000 or more years of bench deposits, the summed collection resembles the composition of contemporary diatom communities.

Biosilica originated both in terrestrial and aquatic habitats. When cell counts are added up, there is an approximate even division, numerically speaking, between 1) diatoms characteristic of aquatic environments and 2) diatoms that are more drought-adapted and may be found either submerged in water or in aerophilous, damp habitats like mud, damp moss or rocks. The first group is a large roster (about 47-53) of species

that in many cases may be represented by only one, two, or a few cells each. These are thought to be diatoms that lived in Coleto Creek and were deposited by overbank flooding. Cell counts and species richness peak in the sandy units and tend to be reduced in the muddy units (Fig. 7.4), perhaps indicating that biosilica was mainly deposited as part of the traction load rather than the suspended load. The chrysophyte cysts, sponge spicules, and probably the phytoliths as well were likely deposited the same way. It is also possible that the differences between the sandy and muddy units are due to turbidity controls on diatom populations. Cell counts may be higher in the sandy units because creek turbidity was lower when these units were being deposited. Species diversity and evenness are slightly depressed in the muddy units (Fig. 7.5). Diatoms and sponge spicules are either absent or present in low density in the Lissie terrace upstream, suggesting that material reworked from the Lissie terrace was not a major source of biosilica for the bench deposits. Two of the species found in the Lissie sample are also entirely absent from the bench deposits, reinforcing this conclusion.

The second group of diatoms is very nearly as numerous but makes up a much smaller list of species (about 18-19), most of which are represented by rather large cell counts (for example, 1387 for *Pinnularia borealis*). Only a few species have cell counts in the 2-10 cell range. These are species characteristic of seasonally desiccated muddy or marshy habitats, and they likely originated at seeps or springs on the floodplain surface. These autochthonous diatoms either lived onsite in groundwater-saturated sediments, or may have been moved by floodwaters a short distance onto the site from nearby seeps or springs upstream. Many of the most abundant species are characteristic of seasonally drying habitats.

Declining Diatoms: Taphonomy or Environmental Change?

Although species diversity and evenness show no well-defined long-term trends, diatom abundance and species richness show a fluctuating, persistent decline from the bottom to the top of the bench stratigraphic sequence. While not quantified, sponge spicules appear to show an equally dramatic decline upsection. Especially notable is a major step decline at the top of stratum 2A (Fig. 7.4). The trend culminates in stratum 2E, where the single sample analyzed was nearly sterile. The percentage of diatoms originating strictly in aquatic habitats also declines over time (Fig. 7.6). As the bench sediments accumulate, drought-adapted species that can live in aerophilous as well as aquatic habitats show increased proportional representation. This pattern could be due to reduced flood frequency (if the floodplain elevation rose while the channel bed remained fixed), but since the elevation difference is not much more than a meter, this hypothesis seems unlikely.

A more likely explanation is that aquatic diatom habitat quality was diminishing during the Younger Dryas because of increased flood force, more frequent and intensified drought, and possibly changing salt or alkalinity levels in Coleto Creek. Certainly, by the time the upper deposits formed in mid- to late Holocene time, environmental conditions for diatom growth must have become very unfavorable. How much of the upsection decline in diatom density, if any, is due to taphonomic decay remains an open question. Sponge spicules show frequent breakage (Figs. 7.20, 7.22) but no noticeable evidence of chemical dissolution. Complete spicules seem to be present mostly in the lower samples. My observations of selected duplicate slides and Barbara Winsborough's observations (Table 7.1) suggest that breakage of both spicules and diatoms tends to increase

upsection, which is consistent with the hypothesis of increasingly violent flooding presented in Chapter 4. Most fragmentation of diatoms (Fig. 7.17) is probably mechanical, but a few appear corroded as well. Sponge spicules survive chemical dissolution better than diatoms because they are more massive (Conley and Schelske 1993). Biosilica dissolution can occur both in anoxic, organic environments like peat bogs (Bennett *et al*. 1991) and in very alkaline environments (Ryves *et al*. 2001; see Battarbee et al. 2001:169-170) for a review. Winsborough (personal communication) has observed that the diatoms present in the bench deposits are chiefly large, robust species that resist breakage and decay well. An experimental study of diatom dissolution by Ryves and others (2001) includes seven or eight species found in the bench deposits, and the abundance of these species in the deposits is roughly proportional to their dissolution resistance, except for *Rhopalodia gibba*, which is more abundant than its resistance rank would seem to suggest.

If postburial chemical dissolution had removed significant numbers of diatoms from the bench sediments, I would expect diatom density to decline downward, not upward, since the deeper sediments appear to have experienced greater groundwater activity and to have been exposed to groundwater longer. Indeed, snails recovered from the deposits show just this pattern, declining markedly in abundance with depth (see Chapter 8). As it happens, the density gradients of snails and diatoms are opposed.

Another possibility that should be considered is the potential for mechanical breakage of biosilica by weathering processes long after burial in overbank sediment. Fissuring of the sediments by shrink-swell processes is more prominent in the upper part

of the stratigraphic section (see Chapter 4). Much more extensive sediment thin section studies than have been done on the bench deposits would be needed to resolve this issue.

Still another possible cause for the upsection decline might be accelerating sedimentation rates, which would probably dilute species richness as well as cell counts, but there is no clear evidence (radiocarbon or otherwise) for greatly accelerated sedimentation rates in the bench sediments. There is a slight trend for upward coarsening of sediment (see Chapter 4), but it is not dramatic. If there is an acceleration of the sedimentation rate, it probably occurred in strata 4 and 5, well after the bench sediments were deposited.

Do the diatom assemblages respond to the alternation of sandy and muddy units, or do they show trends that crosscut the strata? There is a slight tendency for diatom abundance and species richness (Fig. 7.4) and for Axis 1 from the correspondence analysis (Fig. 7.13) to peak in the sandy strata and decline in the muddy strata, but on the other hand, the muddy strata 2A and 2C are well separated by the correspondence analysis and do not cluster on the plot (Fig. 7.12). Only one species, *Nitzschia amphibia*, shows a particular affinity for sandy strata (Fig. 7.7), although several of the other species shown in Fig. 7.7 show increased abundance in the sandy units. Overall, the long-term trends that can be seen in Figs. 7.4 and 7.6 seem more dominant than smaller-scale fluctuations related to the sandy-muddy couplets.

Synopsis

Diatoms probably originated from two sources, 1) Coleto Creek and 2) nearby seeps, springs, or *in situ* growth on the site itself. Declining cell counts and species

richness appear to indicate long-term drying as the bench deposits accumulated, and changes in assemblage composition are more responsive to this long-term trend than to cyclic sedimentation. Diatoms are abundant in the lower part of the bench deposits, less abundant in the upper part, scarce in stratum 2E, and absent in the upper deposits. Sponge spicules were not quantified but probably show a similar history. This contrasts with the report of fairly abundant sponge spicules in the upper 40 cm of deposits at 41 GD 21 (Robinson 1979:112).

Added Note

This chapter could not have been written without the expertise and repeated assistance of Barbara Winsborough, who not only identified and analyzed the diatoms, but provided counsel and information on many occasions.

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Chapter 8: Snails

INTRODUCTION

Snails recovered from the bench deposits offer perhaps the single best source of paleoenvironmental data from the site. They are well preserved, at least in the upper part of the stratigraphic section. Most of them probably represent populations that lived on or near the site. Some may have been deposited by flooding, but the collection is dominated by terrestrial snails, as is the case at most terrace sites. Aquatic snails are rarely found in significant numbers in alluvial archeological sites unless the excavations penetrate some sort of buried swale, oxbow, or other depression. There are about two dozen land snail taxa, a couple of species of amphibious snails, about a half dozen species of aquatic snails, and at least one slug present in the bench deposits.

For comparison with the bench deposits, there are some limited collections of contemporary snails from elsewhere in the catchment, and there is a large collection from the quarter-inch and eighth-inch mesh sample at the Smith Creek Bridge site (Brown 2002). It is the only large, thoroughly studied archeological collection in the immediate area. There is also a very large collection of large-bodied and medium-bodied snails in the quarter-inch screen sample from the blufftop excavations at Berger Bluff, but unfortunately these have never been analyzed. I have examined a few lots in cursory fashion, but there is no comprehensive inventory from the blufftop excavation block. The sampling method has a profound effect on the quality of paleoenvironmental data recoverable from snails, because many species are too small to be retained on quarter-inch mesh, and even the juveniles of most species will fall through the mesh. Good

sampling practice recovers microsnails, medium-bodied, and large-bodied snails alike, using appropriate field techniques.

Snails are usually good paleoenvironmental indicators because they are abundant and preserve well (at least in South Texas), can be treated quantitatively, and are often good indicators of moisture levels and deciduous tree cover. The snail fauna from the bench contrasts significantly with what is known about contemporary populations – there are fewer arid-adapted species in the bench, there are more moisture-dependant species, and there are species now regionally extirpated by climate change. There is also probable evidence for change in geographic ranges of some species. In the following pages I will examine the usefulness of the snail fauna as a paleoenvironmental indicator, first by exploring how biogeography relates to environmental tolerances. I will explore biogeography first at a continental scale, then a statewide scale, then on the scale of habitat or microhabitat preferences. Farther along in the chapter I will present species accounts that list the known habitat preferences for the Berger Bluff species (and it is these accounts that contain the key characteristics for interpretation of the faunal record). I will also discuss specimen recovery methods, shell taphonomy, changes in species diversity, and the relationship between body size, abundance, and environmental tolerances.

BODY SIZE, ABUNDANCE, AND HABITAT SPECIFICITY

Burch and Pearce (1990:Fig. 9.4) classify adult land snails into minute (less than 3 mm), small (3-10 mm), medium (11-30 mm), and large (more than 30 mm) size classes. I prefer instead a three-part division for both land and aquatic snails:

- microsnails (less than about 5 mm in maximum dimension), about 39% of the bench taxa, exemplified by *Gastrocopta*

- medium-bodied snails (about 5-12 mm), about 32% of the bench taxa, exemplified by *Oligyra* and *Praticolella*

- large-bodied snails (over 12 mm), about 29% of the bench taxa, exemplified by *Anguispira* and *Mesomphix*

Figure 8.1 shows abundance plotted against approximate body size. Body size is represented by the maximum dimension (shell height, for conical-shaped snails, and diameter for disk-shaped snails) reported for adults of each species in the malacological literature, not the actual specimens in the collections. Since juveniles and variably-sized adults are disregarded, these are only very rough plots, but they show there is only the weakest of relationships between abundance and size. Three assemblages that will later be discussed in more detail are shown. "A" is a collection of river drift snails from the Brazos River near Columbus and another from the mouth of the Colorado River reported by Branson (1967). I have combined the counts for the two collections and list only the taxa found in the Berger Bluff catchment (about 21 other taxa have been omitted). "B" is a 1998 collection of drift snails from a location upstream from Berger Bluff, on the Preiss Ranch. "C" consists of archeological specimens from two columns (N109 E103 and N110 E102) of matrix samples derived from the bench deposits. Each dot on the scatterplot represents a species, and linear regression trendlines are fitted to each distribution. Assemblage "A" shows almost no relationship between abundance and body size. Assemblages "B" (r^2 =0.19) and "C" (r^2 = 0.01) show a very weak tendency for the smallest species to occur in greater abundance (the linear regression lines curve because the X axis is logarithmic).

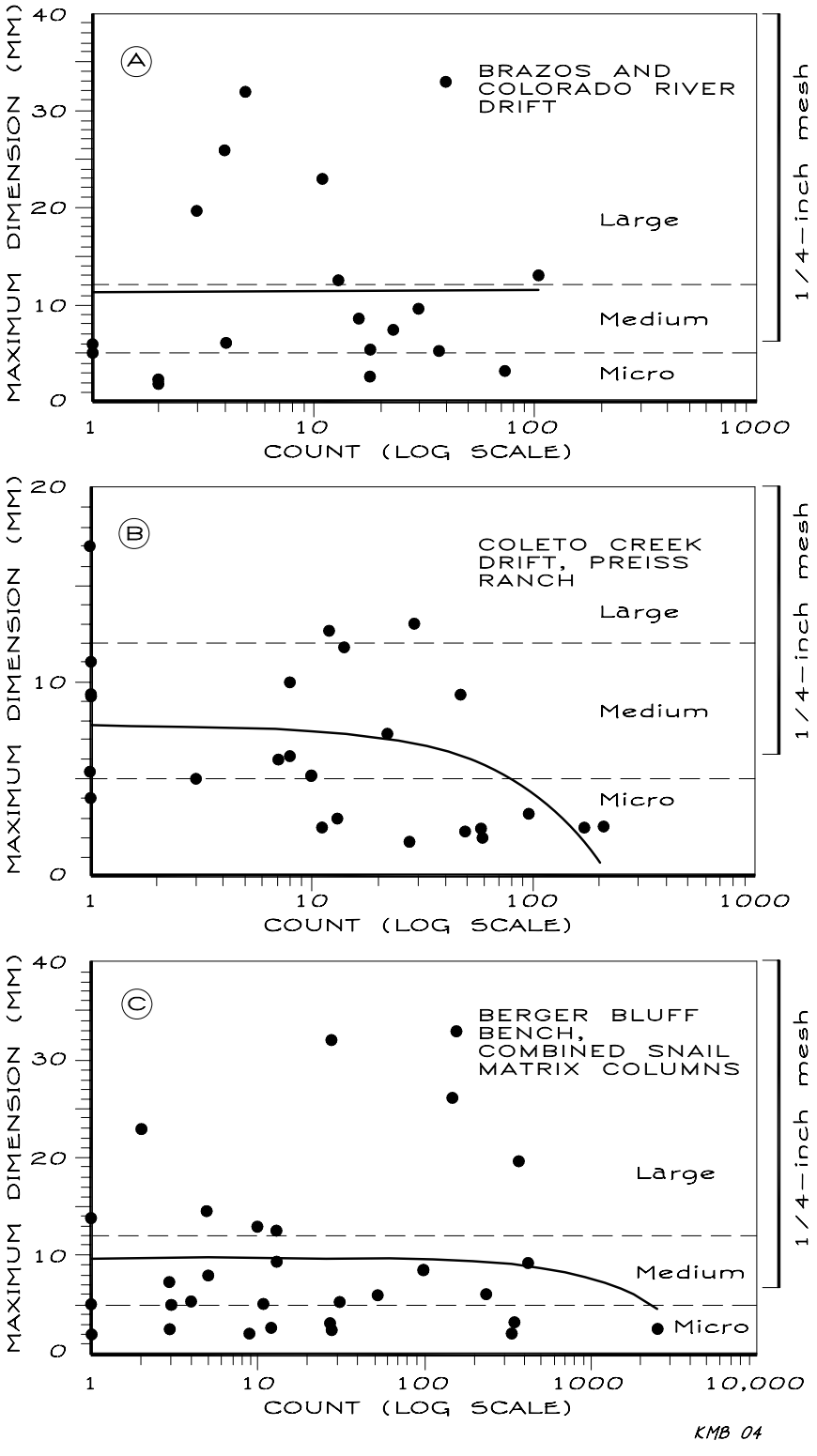
Among vertebrates, there is a well-known tendency for smaller animals to be more abundant than larger animals (Damuth 1981; McMahon and Bonner 1983:227-228), especially when more than one trophic level is involved (mice outnumber lions). Blackburn and Gaston (1994) maintain that animal body size distributions are actually "log right-skewed;" that is, the most abundant animals are not really the smallest ones, but those of intermediate size. According to McClain (2004:328), the relationship between abundance and size is negative when studied at coarse scales, but log-normal or log-uniform when studied at local scales. The snails studied in this chapter all survive on about the same trophic level, and the size-abundance relationship is quite weak. Small vertebrates usually show more species diversity than large ones, too (Hutchinson and MacArthur 1959), but here again the snails depart from this rule, since each size class is roughly a third of the taxa.

For the Brazos-Colorado drift samples, the two most abundant taxa are microsnails; for the Preiss Ranch drift sample, the eight most abundant taxa are microsnails; and for the bench matrix columns, the most abundant taxon is a microsnail, but below these levels, the size-abundance relationship breaks down.

Body size is important because the microsnails include many of the most habitat-diagnostic taxa. The snails found at Berger Bluff vary widely in their diagnostic value. Aquatic snails in the floodplain deposits indicate overbank flooding, but some aquatic taxa (for example, *Planorbella trivolvis*) may be more characteristic of ponded water while others (*Cincinnatia integra*) may be found in running water. The succineids are amphibious and are characteristic of damp ground. Among the terrestrial taxa, many species are characteristic of damp, wooded habitats with abundant leaf litter and downed

wood. These can either be microsnails (like *Gastrocopta contracta*), medium-bodied (like *Euchemotrema leai*), or large bodied (like *Anguispira strongylodes*). Some taxa (such as *Oligyra orbiculata* or *Zonitoides arboreus*) are very cosmopolitan and hardy and can withstand a wide range of environmental conditions, so much so that I tend to regard them as possible indicators of environmental stress.

Figure 8.1 (*following page*). Snail Abundance Plotted Against Body Size. Each dot represents a taxon, and maximum size in millimeters determined from literature sources (height for conical snails, diameter for discoidal snails) is plotted against the count for that taxon. *A*, combined drift samples from the Brazos River near Columbus and another from the mouth of the Colorado River reported by Branson (1967). Only species found in the Berger Bluff bench are plotted. *B*, a drift sample from Coleto Creek on the Preiss Ranch, collected following a flood in the fall of 1998 (note Y axis scale is different). Both of these represent flood-deposited contemporary snails. *C*, archeological specimens from two columns (N109 E103 and N110 E102) of matrix samples from the bench deposits. The X axis on all plots is logarithmic, and the scale on the right shows the mesh size for quarter-inch screening. All these plots show there is either no relationship or a very weak relationship between snail body size and abundance.


A
BRAZOS AND COLORADO RIVER DRIFT
Large
Medium
Micro
1/4-inch mesh
MAXIMUM DIMENSION (MM)
COUNT (LOG SCALE)
B
COLETO CREEK DRIFT, PREISS RANCH
C
BERGER BLUFF BENCH, COMBINED SNAIL MATRIX COLUMNS
KMB 04

BIOGEOGRAPHY

Because there are very few laboratory studies of environmental tolerances for the Berger Bluff species, the environmental significance (and habitat associations) of each species must be assessed by examining its contemporary distribution. One way to begin is by looking at the continent-wide range maps of the various species. This has limited value, because snails really live in microhabitats rather than habitats. For example, marsh snails like *Oxyloma* are found in the arid desert West, but they are confined to seeps and cienegas. The marsh snails are diagnostic of damp ground, but the damp ground is limited to the cienega and is not typical of the entire desert West (Mead 1991:221). Still, it is useful to look at large-scale distributional patterns before examining smaller-scale habitat preferences. The maps that follow are very approximate, because species mapping is very incomplete. At the risk of concealing this incompleteness, I have simplified the maps by drawing boundary lines around major concentrations of reported localities.

Table 8.1 lists geographic ranges of land snails found in the bench deposits. Aquatic snails are not listed because they tend to have nearly continent-wide distributions. The land taxa can be classified into six groups:

- Texas: four large/medium polygyrids (*Mesodon, Polygyra* and *Praticolella* species) are essentially confined to Texas.

- Texas-Florida-Mexico: three species are found mostly in Texas and Florida in hot and humid to arid maritime climatic conditions; they also extend into Nuevo León (Correa Sandoval 1997) and may be limited to the north by winter temperatures (Fig. 8.2).

- Gulf Coastal Plain: two more taxa occupy Texas, Florida, and the mid-south; these range farther north and more inland than the Austral species, and presumably can tolerate colder and drier conditions (Figs. 8.3, 8.4; Austroriparian province of Burch 1962:Fig. 10).

- South-Central United States: three more taxa occupy parts of Texas, Oklahoma, and the Trans-Mississippi South. These presumably tolerate more continental climates, since they are centered more in the interior of the continent (Fig. 8.5). The distribution of *Oligyra orbiculata* outside Texas is poorly documented, however.

- Eastern United States: the largest number of species (13) range over most of the eastern US, including several species of *Gastrocopta* (Fig. 8.6), *Mesodon thyroidus*, *Pupoides albilabris*, and other taxa clearly limited on the west by rainfall, in the north by cold temperatures. These are species tolerant of higher annual rainfall and colder temperatures than is usually characteristic of present-day Texas. Some of these, like *Anguispira*, *Mesodon*, and possibly *Catinella*, reach their southwesternmost limits near Goliad County. Also included is one of the extirpated taxa (*Pomatiopsis lapidaria*, Fig. 8.7) from the bench (the other two are aquatic). Presence of these suggests a climate more like the present eastern US, though one aridity-tolerant species, *Hawaiia minuscula*, extends into Nuevo León (Correa Sandoval 1997).

- Entire United States: one land snail, *Zonitoides arboreus*, is widely distributed throughout the continental US and beyond, much like the aquatic snails. This is the only terrestrial species ranging far into the western US, and its cosmopolitan distribution suggests it is highly adaptable to widely varying climates, including arid ones. It is also very common in the wooded eastern U. S.

Table 8.1: Geographical Ranges of Terrestrial Species Found in the Bench Deposits.

Texas

Mesodon cf. *M. roemeri*
Polygyra mooreana
Polygyra texasiana triodontoides
Praticolella pachyloma [P. berlandieriana]

Texas-Florida-Mexico

Gastrocopta pellucida
Glyphyalinia umbilicata
Pupisoma disocoricola

Gulf Coastal Plain

Anguispira strongylodes
Carychium mexicanum

South-Central United States
Mesomphix friabilis
Oligyra orbiculata
Rabdotus dealbatus [R. mooreana]

Eastern United States

Catinella vermeta
Euchemotrema leai
Gastrocopta armifera
Gastrocopta contracta
Gastrocopta pentodon
Gastrocopta procera
Gastrocopta tappaniana
Hawaiia minuscula
Helicodiscus singleyanus (?)
Mesodon thyroidus
Pomatiopsis lapidaria
Pupoides albilabris
Strobilops texasiana

Entire United States

Zonitoides arboreus

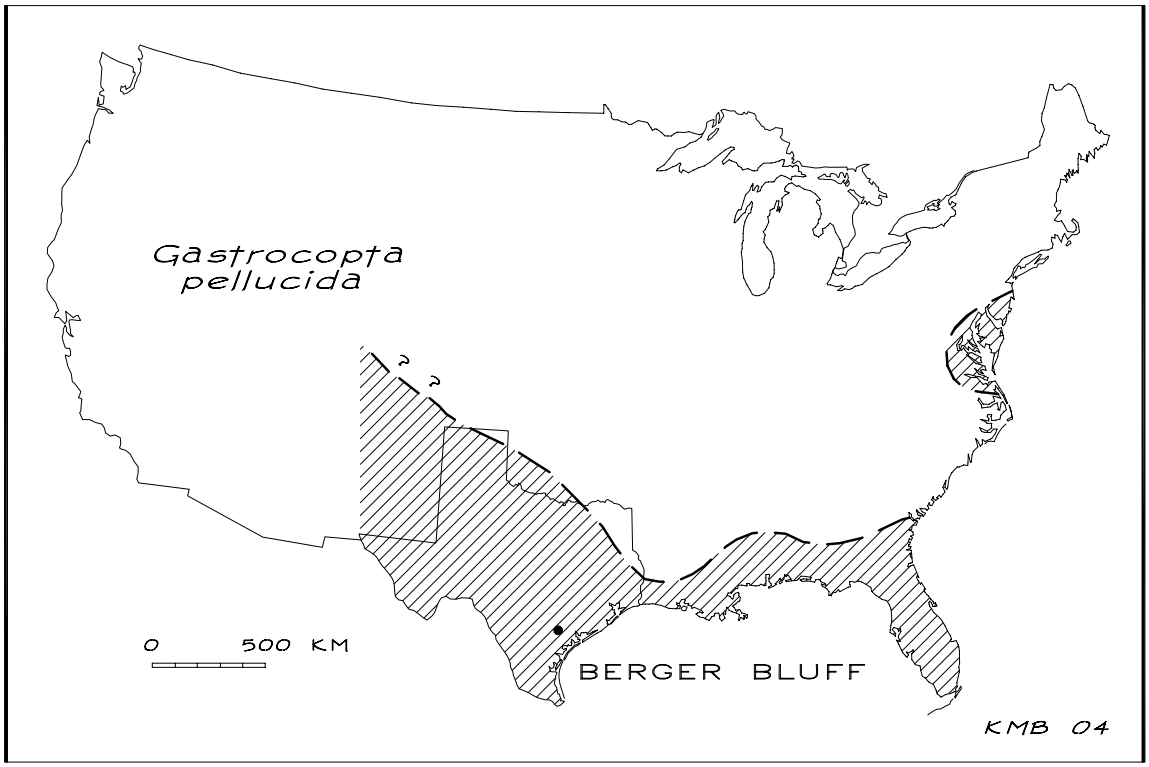


Figure 8.2. Approximate Range of *Gastrocopta pellucida* as Mapped by Hubricht. Map adapted and generalized from Hubricht (1985:Map 49). Range actually extends into Oklahoma, Kansas, Colorado, New Mexico (Metcalf 1984:5) and to the eastern side of Utah (Oliver and Bosworth 1999). This is a rather arid-adapted microsnail.

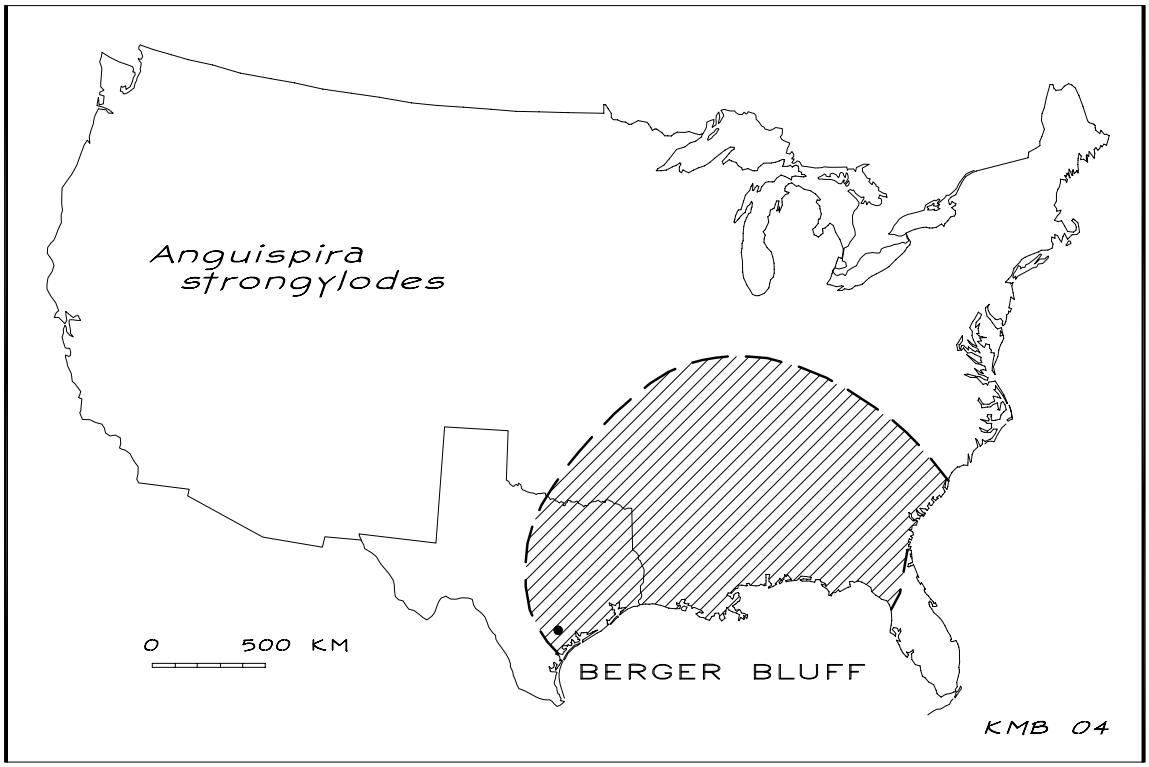


Figure 8.3. Approximate Range of *Anguispira strongylodes* as Mapped by Hubricht. Map adapted and generalized from Hubricht (1985:Map 159). This is a large-bodied woodland snail.

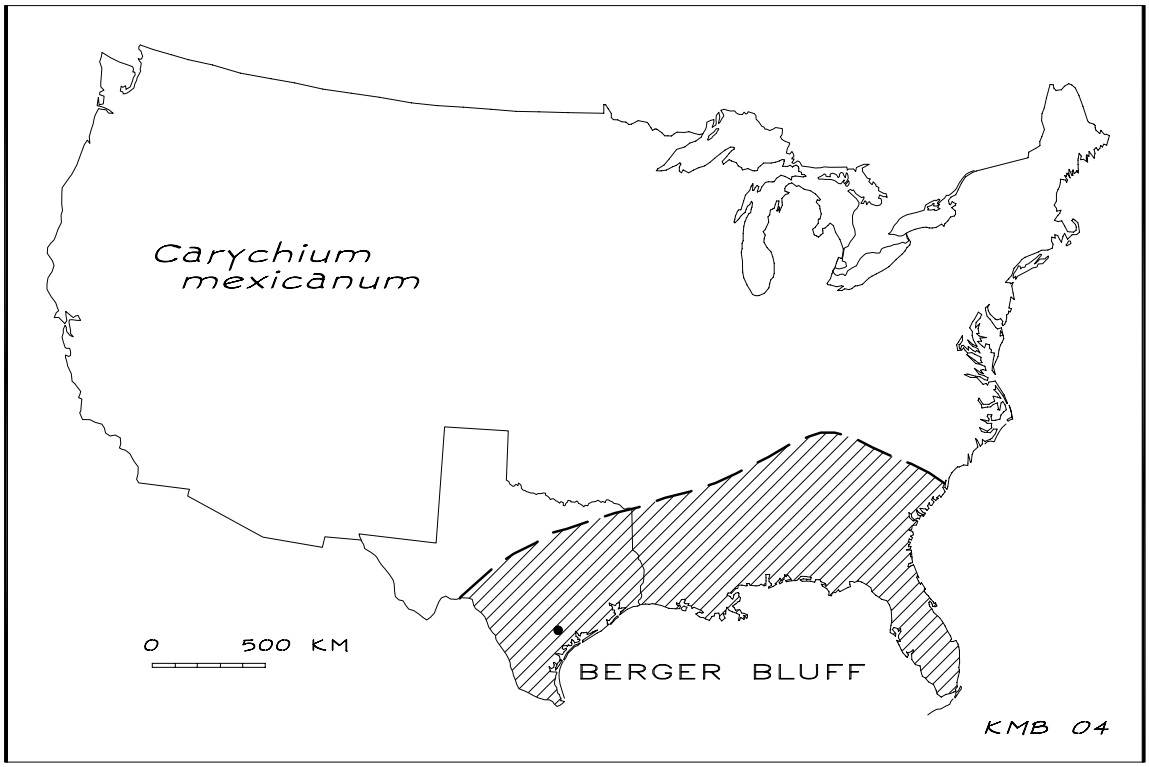


Figure 8.4. Approximate Range of *Carychium mexicanum* as Mapped by Hubricht. Map adapted and generalized from Hubricht (1985:Map 14). Compare with Fig. 8.8. This is a microsnail found on wet floodplains. Range also extends into Nuevo León, Tamaulipas and San Luis Potosí in Mexico (Correa Sandoval 2003). Its northern limit corresponds very roughly to a mean daily minimum temperature of about 50-55º F.

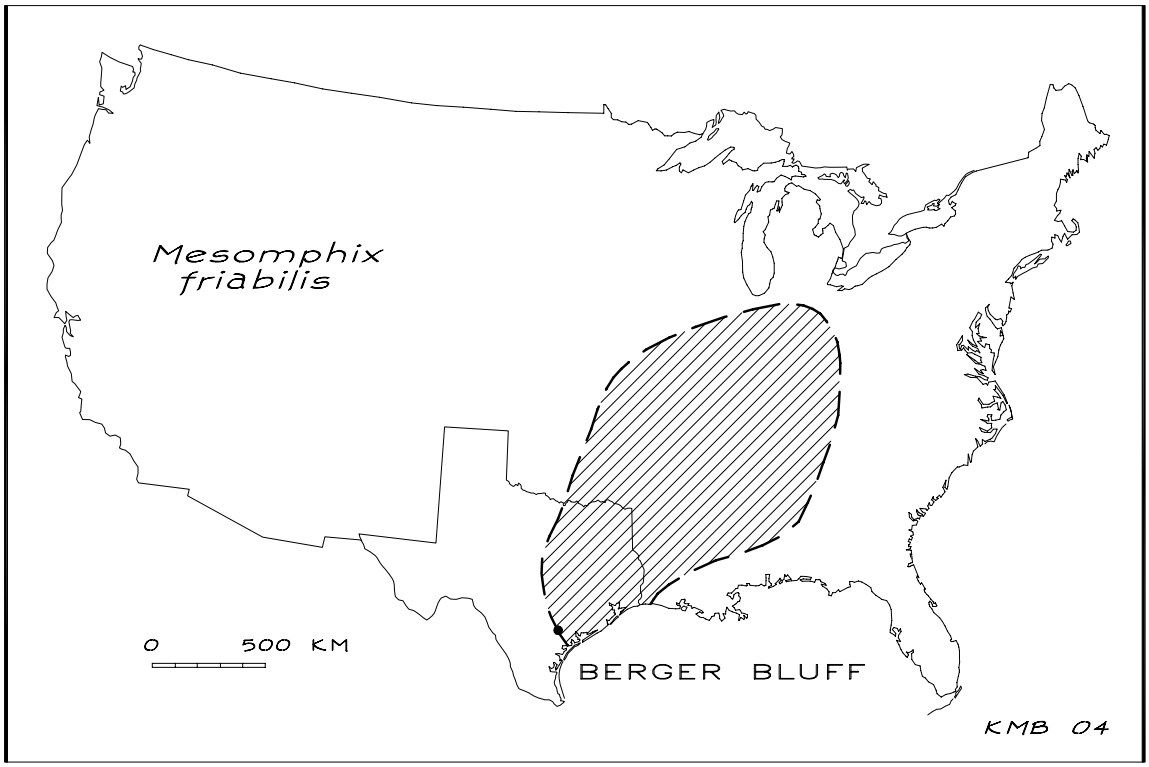


Figure 8.5. Approximate Range of *Mesomphix friabilis* as Mapped by Hubricht. Map adapted and generalized from Hubricht (1985:Map 239). This is another large-bodied woodland snail.

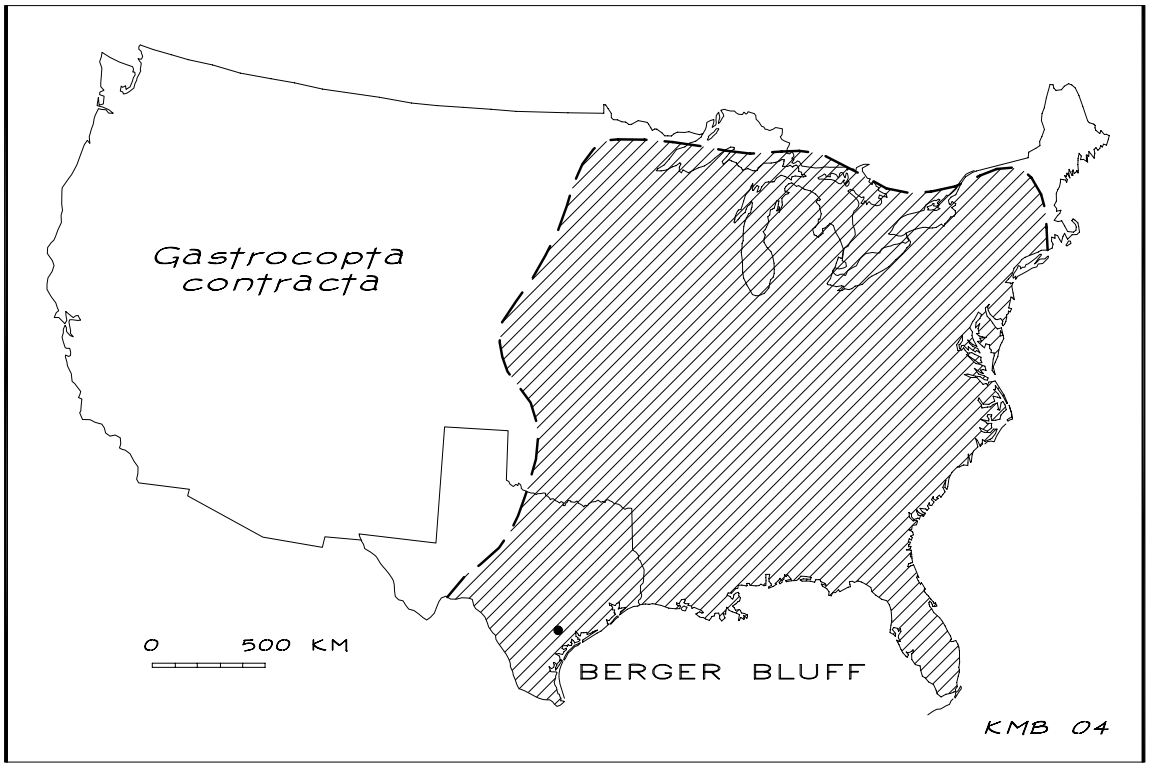


Figure 8.6. Approximate Range of *Gastrocopta contracta* as Mapped by Hubricht. Map adapted and generalized from Hubricht (1985:Map 42). Compare with Figure 8.9. This is a microsnail common to the bench deposits. Its distribution actually extends into Ontario and Manitoba in Canada (Oughton 1948:50) and Nuevo León, Tamaulipas and San Luis Potosí in Mexico (Correa Sandoval 2003). Its western limit corresponds to the 5-inch mean total precipitation isohyet for September.

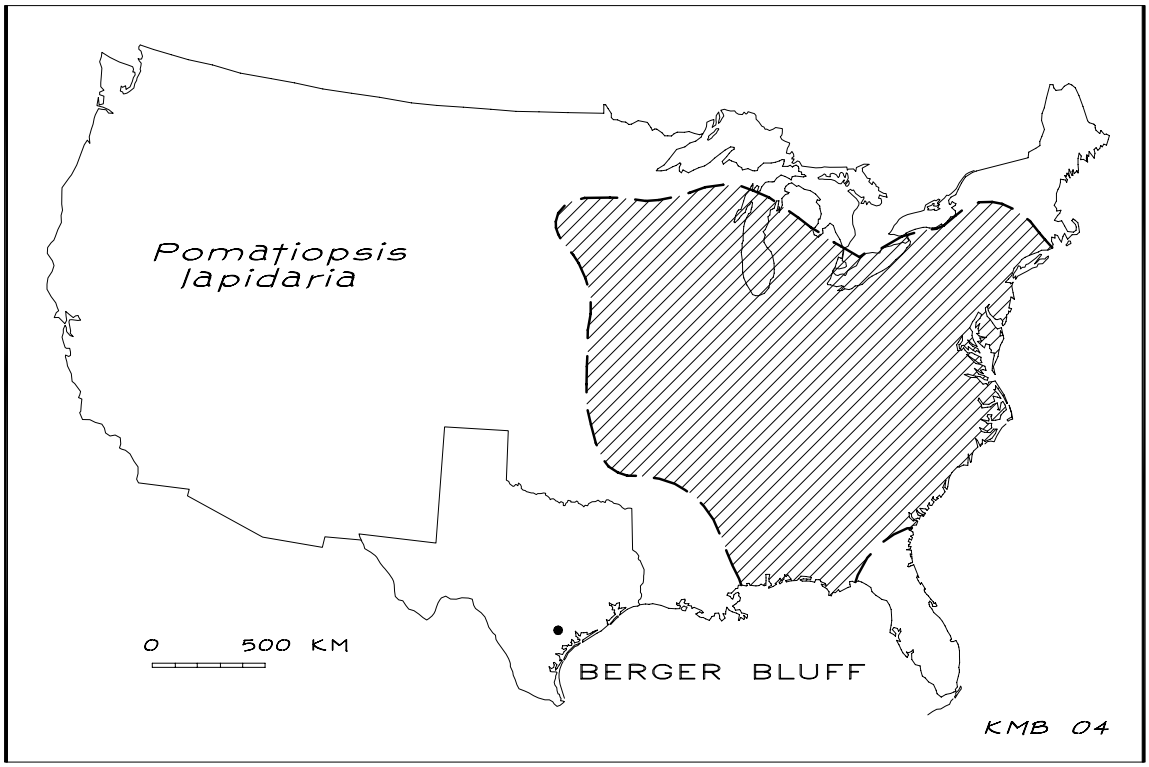


Figure 8.7. Approximate Range of *Pomatiopsis lapidaria* as Mapped by Hubricht. Map adapted and generalized from Hubricht (1985:Map 11). This amphibious marsh microsnail is present in the bench deposits, but now extirpated in Texas.

If we narrow the focus from continent-wide to statewide geographic ranges, it is possible to be even more specific about some environmental tolerances, because the distributions of most of these species are actually better mapped in Texas than elsewhere (Figs 8.8-8.16 and 8.18 illustrate some of the Berger Bluff species). In some cases, part of the range limits for a species can be matched to a band of mean annual rainfall isohyets, or perhaps to a minimum temperature isotherm. Each species has a minimum and maximum annual precipitation that is characteristic of its range, and because Texas is the southwestern limit for many of these species, it is sometimes possible to specify roughly the minimum annual precipitation for the species. For example, the western range limit for *Mesodon thyroidus* in Texas corresponds roughly to the 32-36 inch rainfall isohyets, or roughly 80-90 cm of rainfall per year (Fig. 8.12; Larkin and Bomar 1983:18). Actually, for this species, the limiting factor may be the western limit of broad-leafed deciduous trees which require at least 80-90 cm of annual rainfall, and which *Mesodon* depends on for leaf litter habitat. The maximum precipitation limit is more difficult to specify, and for most species can be found somewhere to the east or northeast in some distant part of the eastern United States.

A glance at geologic, vegetation, rainfall and temperature maps for Texas shows that units of the first three variables are generally arranged in curving bands that roughly parallel the Gulf Coast, while the temperature isotherms tend to run east-west, orthogonal to the others. The western limits of many of these snail species roughly coincide with some of these major geologic, vegetation, or rainfall bands and so it is difficult to specify which – soil, vegetation, or moisture – controls the species boundary, and in fact all three are probably interrelated. Annual rainfall and soil texture may determine the extent of deciduous woodland, which in turn determines the range of the species. Because Texas has a mild climate, temperature seldom seems to be a limiting factor here. One possible exception is *Rabdotus alternatus*. This species is not found in the bench deposits or in the

local modern fauna (whether it occurs in strata 4 and 5 is unknown), but it occurs in Holocene deposits a short distance upstream at the Smith Creek Bridge site, where I suggested (Brown 2002:237-238) it had expanded its range during the Hypsithermal. Figure 8.17 shows the northern limit as mapped by Fullington and Pratt (1974:Fig. 5) compared with the 68-70° F mean annual temperature isotherms. The congeneric *R. dealbatus* (Fig. 8.18) seems to be limited by moisture and calcium availability.

Examination of the maps shows some differences between the species. For example, *Pupisoma dioscoricola* (Fig. 8.15), *Mesodon thyroidus* (Fig. 8.12*), Praticolella pachyloma* (Fig. 8.14), *Anguispira strongylodes* (Fig. 8.3), and *Mesomphix friabilis* (Fig. 8.5) are clearly much more restricted to the wetter eastern part of the state than are widespread species like *Gastrocopta pellucida* (Figs. 8.2, 8.10 or *Oligyra orbiculata* (Fig. 8.13), which cover the eastern part of the state but also extend well into the drier western part. The mapped distribution for *G. pellucida* is actually misleading, because it extends into Oklahoma (Wyckoff, Theler, and Carter 1997:Table 4), Kansas (Leonard 1959:1801-81; Franzen and Leonard 1947), Colorado, New Mexico and Arizona (Bequaert and Miller (1973:171) and just into the eastern edge of Utah (Oliver and Bosworth (1999:Fig. 50) as well. In Mexico, it extends at least as far south as Jalisco and San Luís Potosí. While examining these maps, it is important to remember that the mapping is very generalized and incomplete, and the snails actually live in habitats or microhabitats embedded in the larger biome.

The history of molluscan zoogeographic ranges (both terrestrial and aquatic) on the Southern Plains since the Late Pleistocene has been one of contraction toward the east or northeast as regional climate warmed and dried both during and after the Younger Dryas. The same process has been documented for the central Plains, except that some species withdrew to the Rocky Mountains instead of eastward (Wells and Stewart 1987).

Viewed from the vantage point of individual archeological or paleontological sites, range contraction appears as progressive extirpation of species (Pierce 1987:Fig. 6.1). According to Neck (1995a:284), the modern land snail fauna of the southern Plains includes 24 terrestrial species (including one slug) compared to 69 species (with two species of slugs) earlier in the Quaternary. The aquatic snail fauna consists of nine species, compared to 57 aquatic species earlier in the Quaternary. At the Lake Theo site, Neck has recognized five sequential stage of species deletion from the early Younger Dryas to the present (Neck 1987a:Table 3), which he attributes chiefly to declining precipitation and loss of gallery woodland.

Several of the contemporary species present at Berger Bluff appear to be at the southwesternmost limit of their geographic range. The clearest examples are *Anguispira strongylodes*, *Mesomphix friabilis*, *Mesodon thyroidus*, and possibly *Catinella vermet*a and *Carychium mexicanum* (Figs. 8.3, 8.5, 8.12, 8.4; Hubricht 1985:Map 134). Their distribution suggests that as global warming progresses, their ranges will withdraw to the northeast into the woodland of East Texas, resulting in local extirpation for these species. Indeed, I have not seen living examples of *Anguispira* or *Mesomphix* in the catchment, although Neck (1977) reports them present in the area. In addition to these species, there are several others whose ranges extend into the western part of Texas, but are also occur even farther to the west as fossils, according to mapping by Hubricht (1985). Included in this group are *Gastrocopta pentodon*, *Strobilops texasiana*, *Euchemotrema leai*, *Gastrocopta tappaniana*, and perhaps *Polygyra texasiana* (Hubricht 1985:Maps 61, 104, 427, 57, and 373). These appear to represent species that have contracted their ranges to the eastward during the Quaternary, but not so far eastward as to approach Berger Bluff.

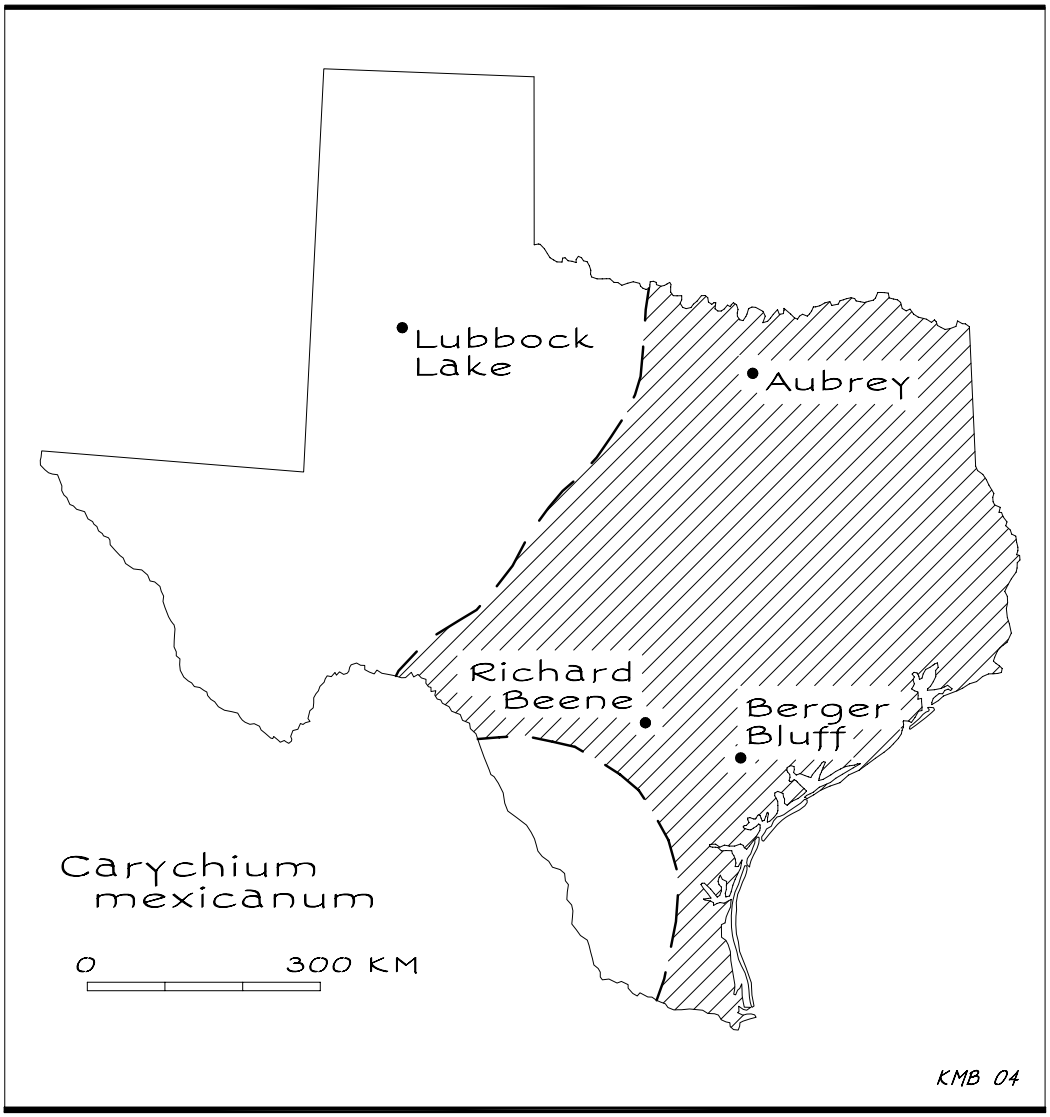


Figure 8.8. Approximate Range of *Carychium mexicanum* in Texas as Mapped by Fullington and Pratt. Map adapted and generalized from Fullington and Pratt (1974:Fig. 3). The locations of Berger Bluff and three other early snail faunas are shown. Compare with Fig. 8.4.

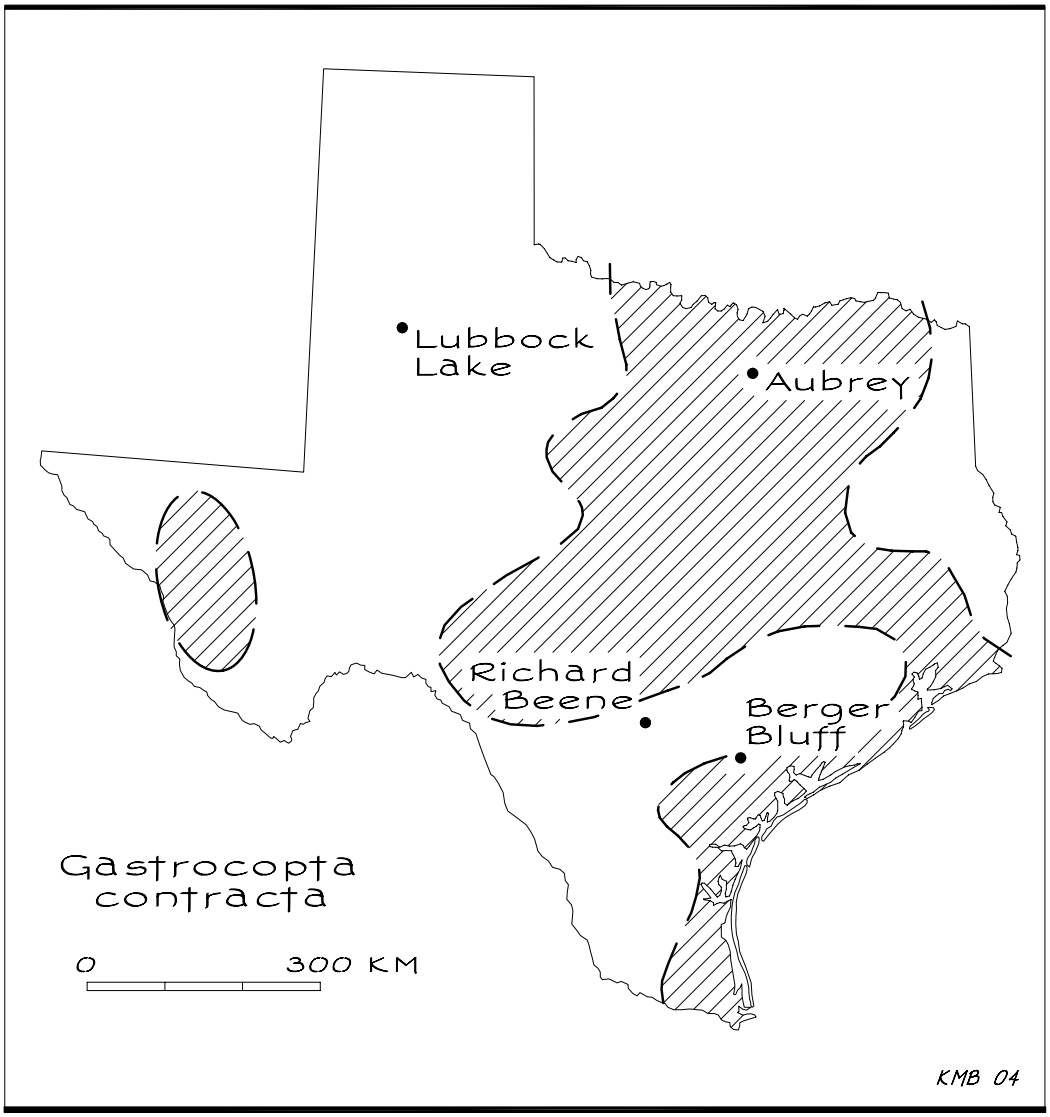


Figure 8.9. Approximate Range of *Gastrocopta contracta* in Texas as Mapped by Cheatum and Fullington. Map adapted and generalized from Cheatum and Fullington (1973:Fig. 3). The locations of Berger Bluff and three other early snail faunas are shown. Compare with Fig. 8.6. Note irregular distribution and alpine population in the Big Bend. Range also extends into Nuevo León, Tamaulipas and San Luis Potosí in Mexico (Correa Sandoval 2003).

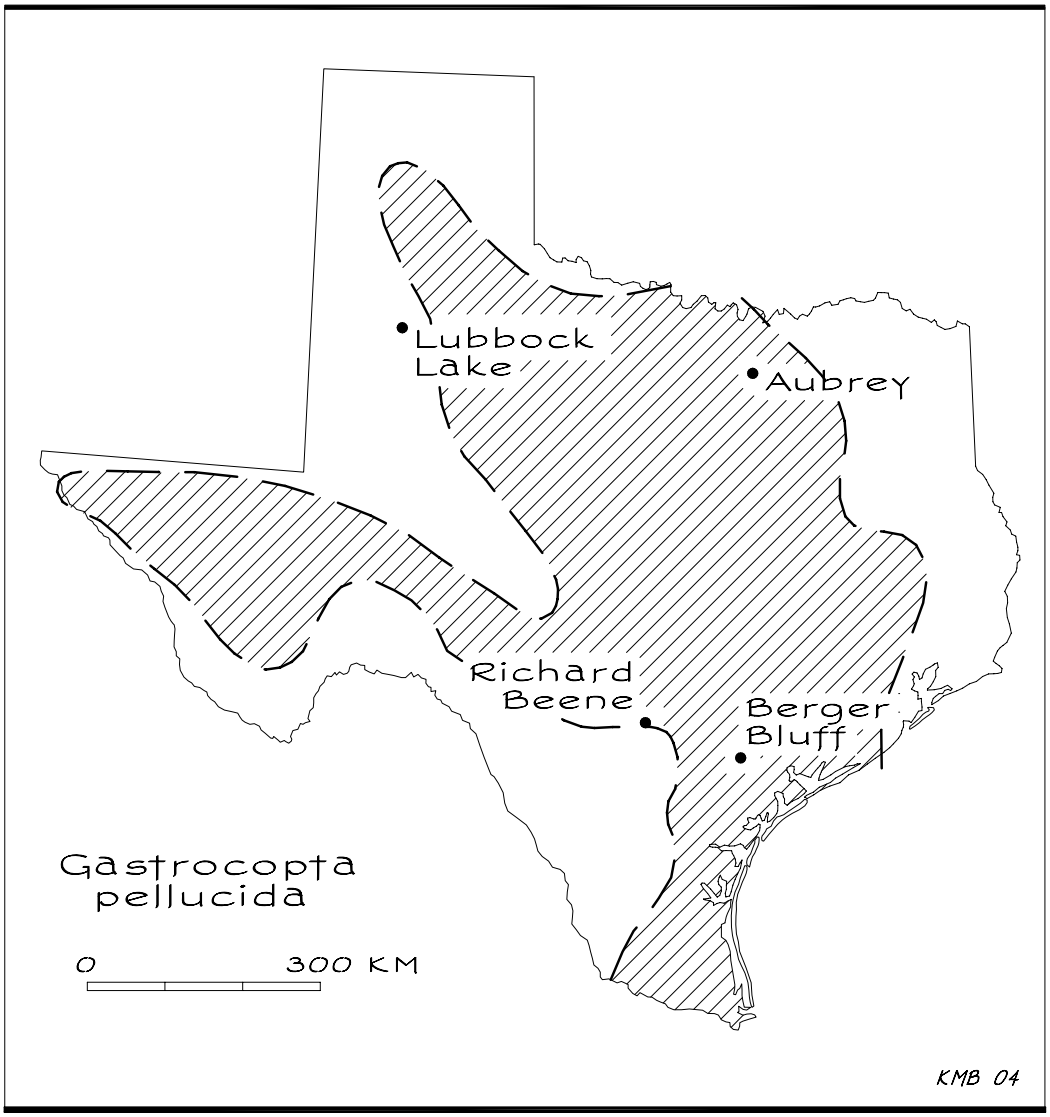


Figure 8.10. Approximate Range of *Gastrocopta pellucida* in Texas as Mapped by Cheatum and Fullington. Map adapted and generalized from Cheatum and Fullington (1973:Fig. 5). The locations of Berger Bluff and three other early snail faunas are shown. The boundary shown here is not very accurate. It actually extends into Oklahoma, Colorado, and New Mexico and into Nuevo León, Tamaulipas and San Luis Potosí in Mexico (Correa Sandoval 2003). Compare with Figure 8.2. Note that this is a more arid-tolerant snail than the congeneric *G. contracta*.

Figure 8.11. Approximate Range of *Euchemotrema leai* in Texas as Mapped by Cheatum and Fullington. Map adapted and generalized from Cheatum and Fullington (1971:Fig. 15). The locations of Berger Bluff and three other early snail faunas are shown. This is a medium-bodied woodland snail.

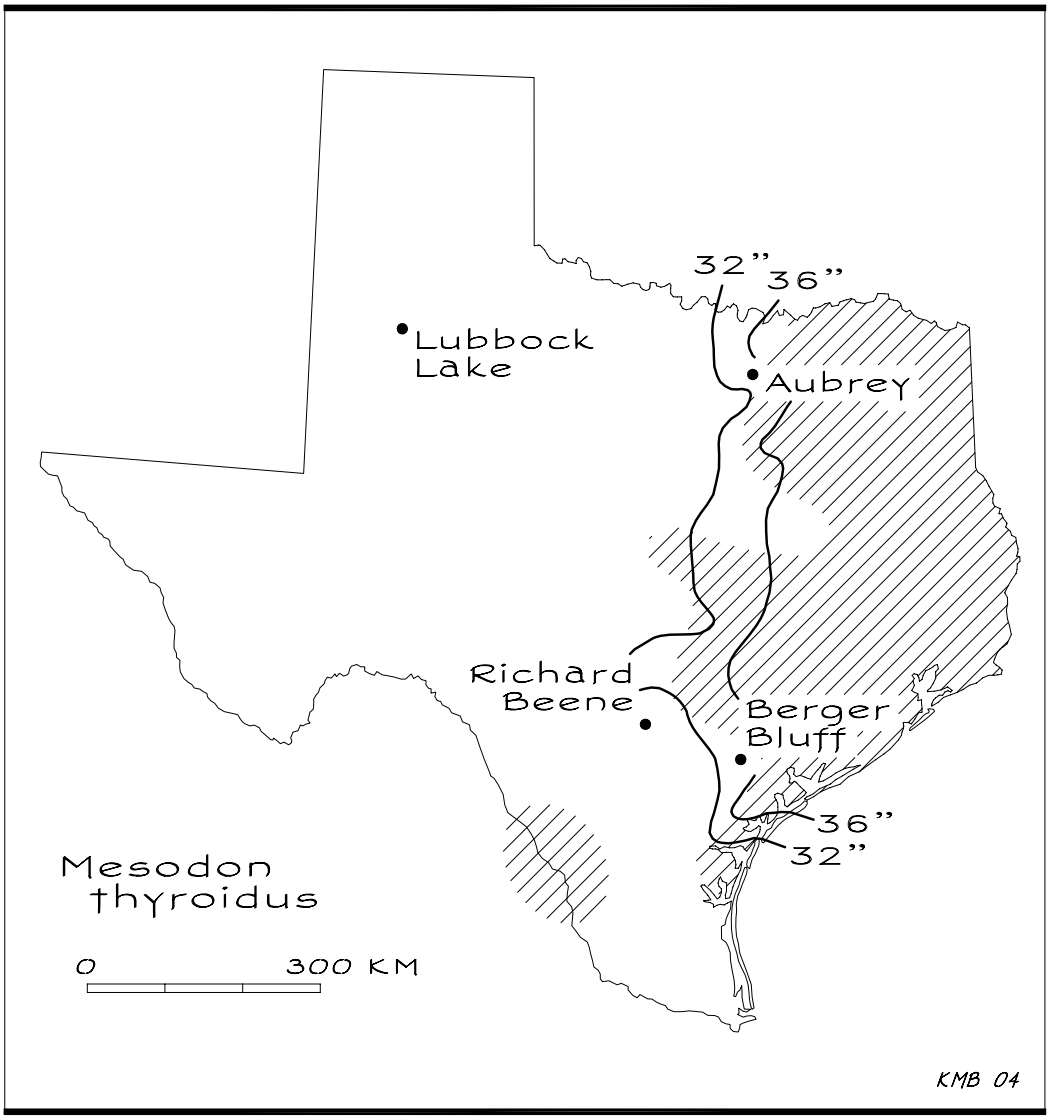


Figure 8.12. Approximate Range of *Mesodon thyroidus* in Texas as Mapped by Cheatum and Fullington. Map adapted and generalized from Cheatum and Fullington (1971:Fig. 13). The locations of Berger Bluff and three other early snail faunas are shown, along with the 32-inch and 36-inch mean annual rainfall isohyets (1951-1980 data from Larkin and Bomar 1983:18). Western limit of this snail seems to be determined by deciduous woodland or moisture limits.

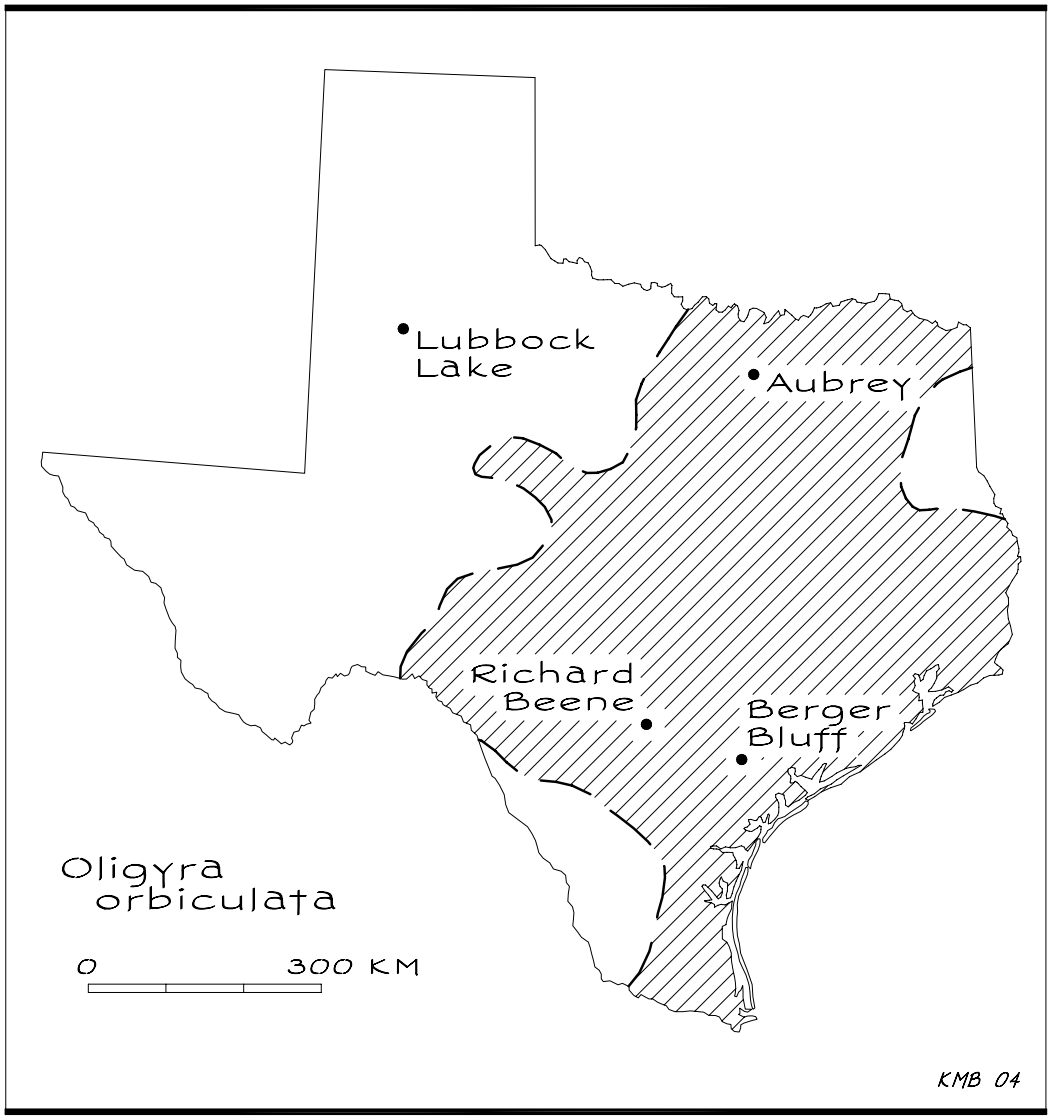


Figure 8.13. Approximate Range of *Oligyra orbiculata* in Texas as Mapped by Fullington and Pratt. Map adapted and generalized from Fullington and Pratt (1974:Fig. 1). The locations of Berger Bluff and three other early snail faunas are shown. This is a very abundant, cosmopolitan, hardy medium-bodied operculate species. Range extends into Nuevo León, Tamaulipas and San Luis Potosí in Mexico (Correa Sandoval 2003).

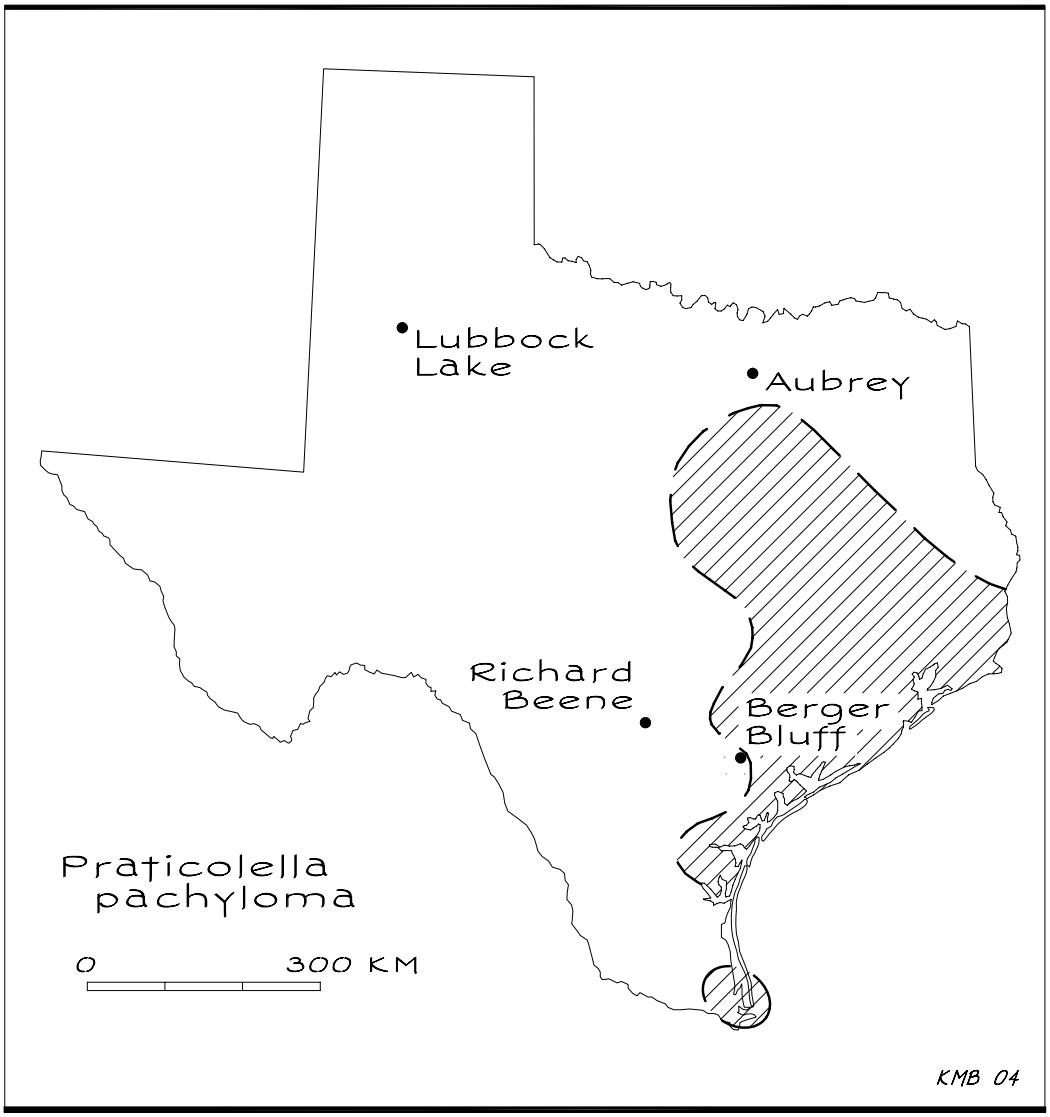


Figure 8.14. Approximate Range of *Praticolella pachyloma* in Texas as Mapped by Cheatum and Fullington. Map adapted and generalized from Cheatum and Fullington (1971:Fig. 12). The locations of Berger Bluff and three other early snail faunas are shown. The range as shown by Hubricht (1983:Map 3) is slightly different. This is a medium-bodied polygyrid, and one of the few species that is nearly endemic to Texas.

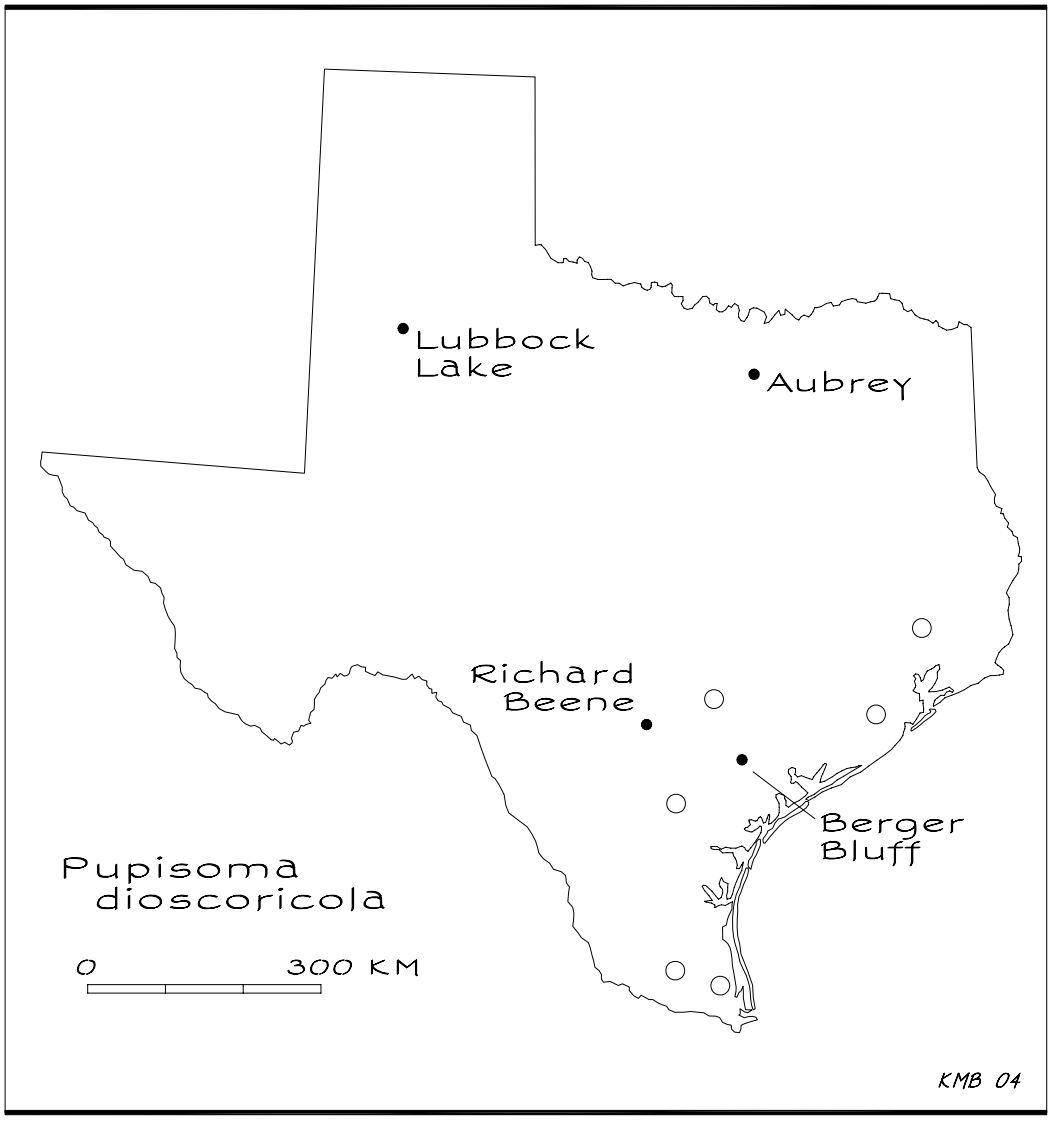


Figure 8.15. Approximate Range of *Pupisoma dioscoricola* in Texas as Mapped by Cheatum and Fullington. Map adapted and generalized from Cheatum and Fullington (1973:Fig. 8). The locations of Berger Bluff and three other early snail faunas are shown. Open circles represent the only known locations for contemporary specimens. Range also extends into Nuevo León, Tamaulipas and San Luis Potosí in Mexico (Correa Sandoval 2003).

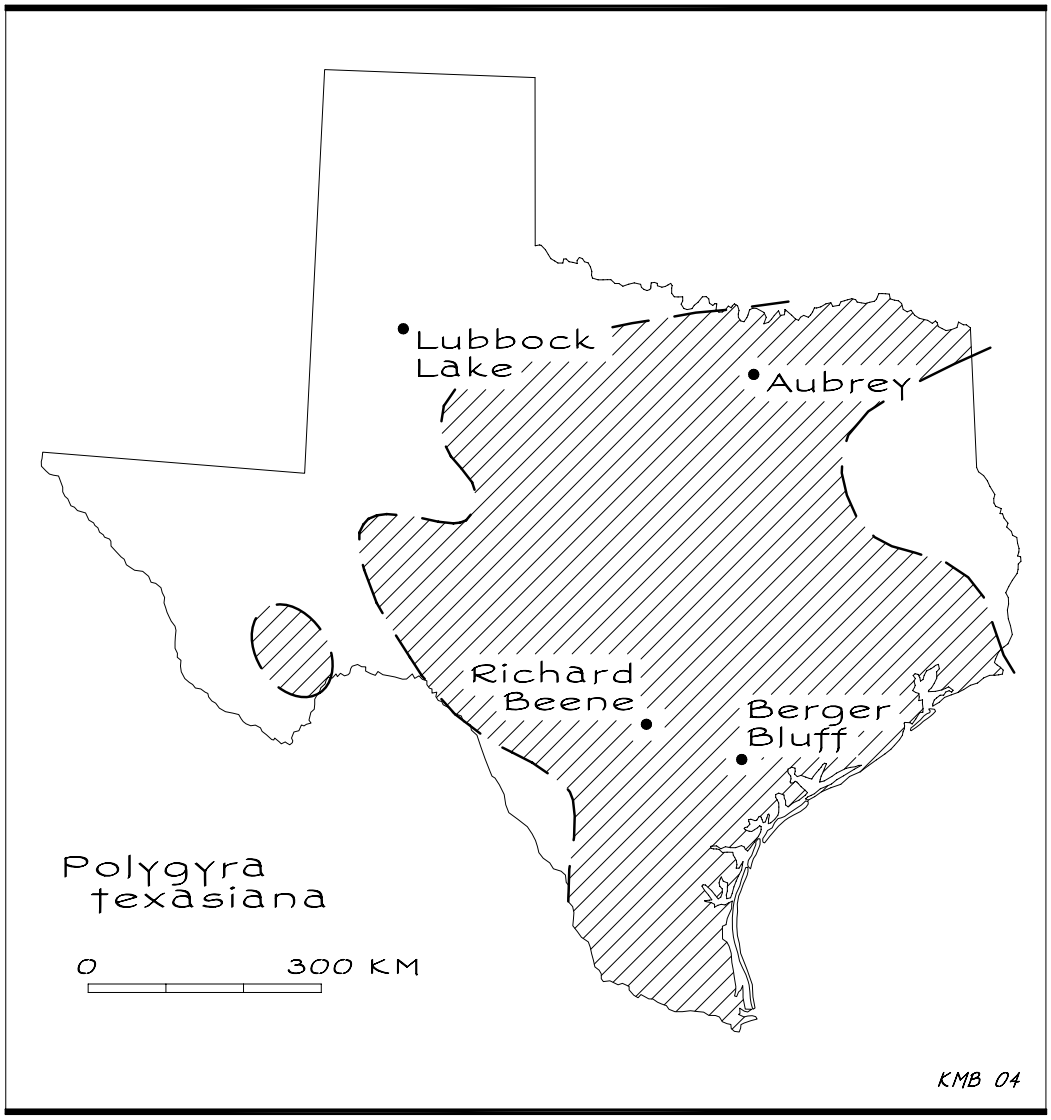


Figure 8.16. Approximate Range of *Polygyra texasiana texasiana* in Texas as Mapped by Cheatum and Fullington. Map adapted and generalized from Cheatum and Fullington (1971:Fig. 8). The locations of Berger Bluff and three other early snail faunas are shown. Compare with Fig. 8.50, which shows the approximate range for *Polygyra texasiana triodontoides*, the subspecies believed to be present at Berger Bluff.

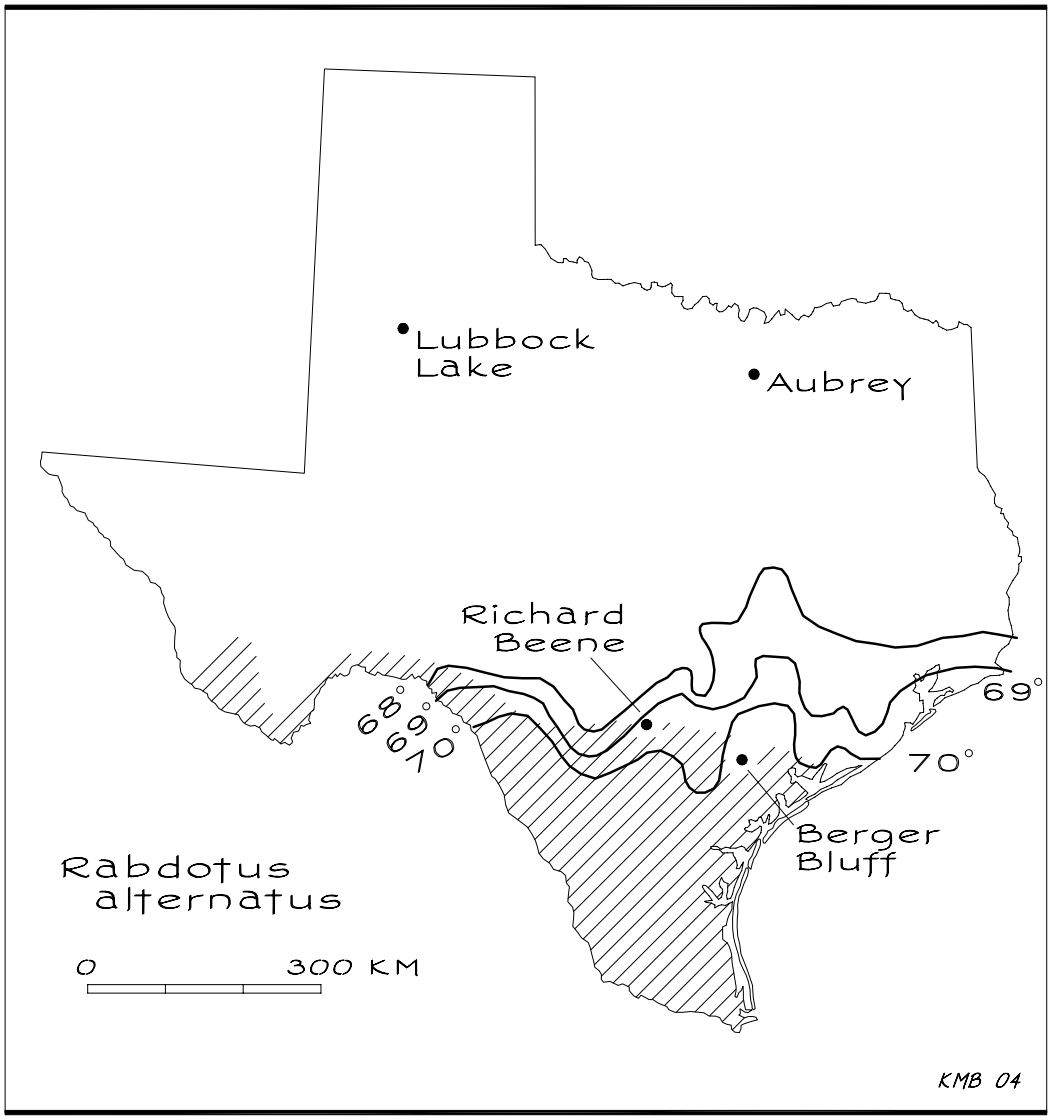


Figure 8.17. Approximate Range of *Rabdotus alternatus* in Texas as Mapped by Fullington and Pratt. Map adapted and generalized from Fullington and Pratt (1974:Fig. 5). The locations of Berger Bluff and three other early snail faunas are shown, along with the 69-70º F mean annual temperature isotherms (1951-1980 data from Larkin and Bomar 1983:50). This species does not occur either in the bench deposits or in the modern local fauna (despite the mapping shown here), but was found throughout Holocene deposits at the Smith Creek Bridge site. Its northern limit seems to be determined by minimum temperatures, and it probably expanded its range into the catchment during the Hypsithermal.

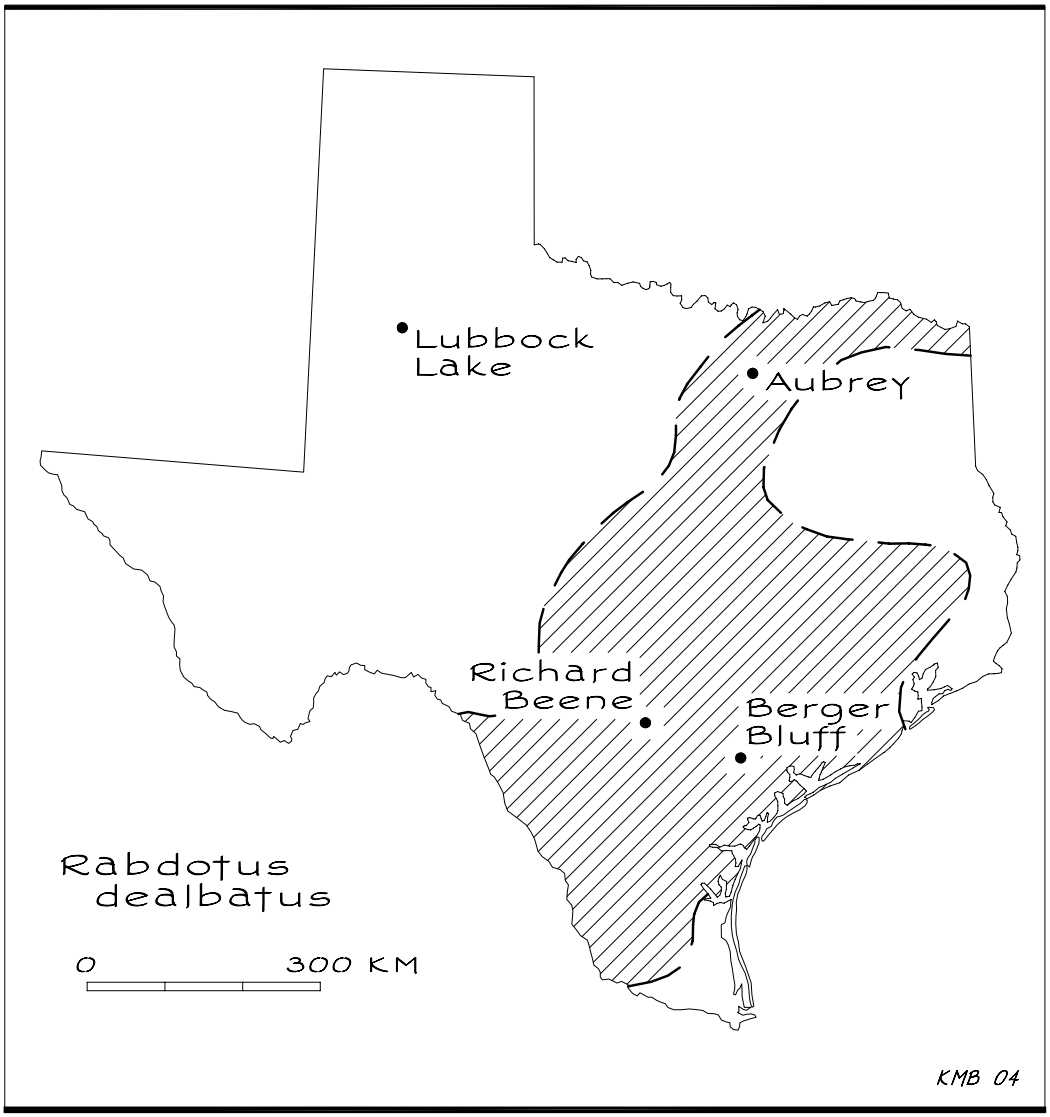


Figure 8.18. Approximate Range of *Rabdotus dealbatus* in Texas as Mapped by Fullington and Pratt. Map adapted and generalized from Fullington and Pratt (1974:Fig. 6). The locations of Berger Bluff and three other early snail faunas are shown. This is possibly the chief species of *Rabdotus* found in the bench deposits.

More useful still are regional or local-scale surveys of snail populations. These often use traps for live snails, or involve the collection of litter samples from small (usually 50 cm square) quadrats arranged on grids or transects. The data from surveys like these are more useful because the actual microhabitat preferences of the snails can be discerned, and living snails can more easily be discriminated from subfossil shells. The surveys usually produce counts and densities of individuals, and when reproducible methods are used, species richness can be reliably determined. Some of these studies attempt to relate distributions to biome, vegetation density rainfall, temperature, soil calcium content, pH, or other factors (Goodfriend 1992:Table 1). Examples of these quantitative or semi-quantitative surveys are the Southern Plains Gastropod Survey (Wyckoff, Theler, and Carter 1997), surveys in Kaufman County, Texas (Logsdon 1967), Alberta (Kralka 1986; Boag and Wishart 1982), Kansas (Basch, Bainer and Wilhm 1961), Tennessee (Coney *et al*. 1982; Getz and Uetz 1994), Minnesota (Coulter, White, and Nordlie 1963), Wisconsin (Theler 1997; Nekola and Smith 1999), the Great Lakes region (Nekola 2003), Maryland (Hotopp 2002), Norway (Vollan 2003), and Germany (Martin and Sommer 2004a, 2004 b).

THE SOUTHERN PLAINS GASTROPOD SURVEY

The Southern Plains Gastropod Survey was done in 1995-96 and is one of the most useful surveys for interpreting the Berger Bluff snail record because it allows us to see how snail abundance and species richness respond to a major moisture gradient across the North American midcontinent. Wyckoff, Theler and Carter surveyed land snail assemblages in a 400 mile long (640 km), 60 mile wide corridor extending from Kay County in eastern Oklahoma to Colfax County in northeastern New Mexico, in the foothills of the Rocky Mountains. Eleven localities were sampled, recovering over 34,000 snails representing 24 species, at least nine of which are also found at Berger Bluff. Each

locality was about 400 m or less in diameter, sampled with transects consisting of three 50 x 50 cm quadrats spaced about 10-20 m apart. One to six transects were collected per locality, for a total of 34 (and 114 quadrats) for the entire survey (Wyckoff, Theler, and Carter 1997:Table 4). The actual samples consist of one to two liters of organic detritus and up to 2 cm of the underlying soil from the surface of the quadrat, floated in water and then sieved through a #40 (0.425 mm) geologic sieve. In some cases half samples (split with a sample splitter) were analyzed. Surrounding vegetation, and topography were recorded, and soils were field-tested for texture, consistency, moisture content, and pH (Wyckoff, Theler, and Carter 1997:7, Fig. 4).

The survey provided a wealth of information that can be used to help interpret the Berger Bluff snail assemblage. The six taxa with the highest frequency of recovery (*Pupoides albilabris, Gastrocopta procera, G. pellucida, Hawaiia minuscula*, Succineidae, and *Helicodiscus singleyanus*) are all found in the bench deposits at Berger Bluff, although most have much lower abundance rankings there. Except for the succineids, all are microsnails adapted to the open, grassy, xeric habitats found in the survey corridor, which has mean annual rainfall varying from about 40 cm in New Mexico to 92 cm at the eastern end in Oklahoma (the latter is about the same as for the Berger Bluff catchment). In fact, nearly all the snails recovered by the Southern Plains survey are microsnails. The survey area is largely treeless, and large-bodied woodland snails are absent.

Figure 8.19 shows how snail distribution plots against the westward-declining rainfall gradient from eastern Oklahoma into New Mexico. In both panels, the horizontal axis is longitude, from the 96th meridian westward to the 105th meridian. Mean annual rainfall is plotted as a heavy line. In panel “A,” the presence or absence of 11 taxa that are also found in the bench deposits is shown for the 11 localities (Succineidae are

represented in the bench by *Catinella vermeta*, and the slug species is unidentified, but could possibly be *Deroceras laeve*). Three taxa on the lower right occurring only at the easternmost locality (*Gastrocopta armifera*, *G. contracta*, and *G. pentodon*) appear to be less arid-tolerant than the rest. Panel "B" repeats the rainfall plot (scaled on the left), along with curves for species richness (average number of species per collection locality) and density (average number of snails per square meter for a locality), with separate scales on the right side. What Figure 8.19 shows is that although regional moisture levels decline from east to west, population density and species richness decline in uneven fashion. There are obvious peaks for density and richness representing the Kubik, Burnham, and Black Mesa localities. Average species richness varies from 1 to 8 (maximum range, 0 to 14), and average density varies dramatically from 13 to 4763 individuals/m^2 (Wyckoff, Theler, and Carter 1997:Table 6). The survey shows that although snail populations respond to large-scale environmental gradients, there are "hotspots" of density and species richness, embedded in the larger patterns, and representing more localized habitats (here, mostly rock ledges) favorable for snails. To summarize, snails are good environmental proxies, but are even better habitat proxies.

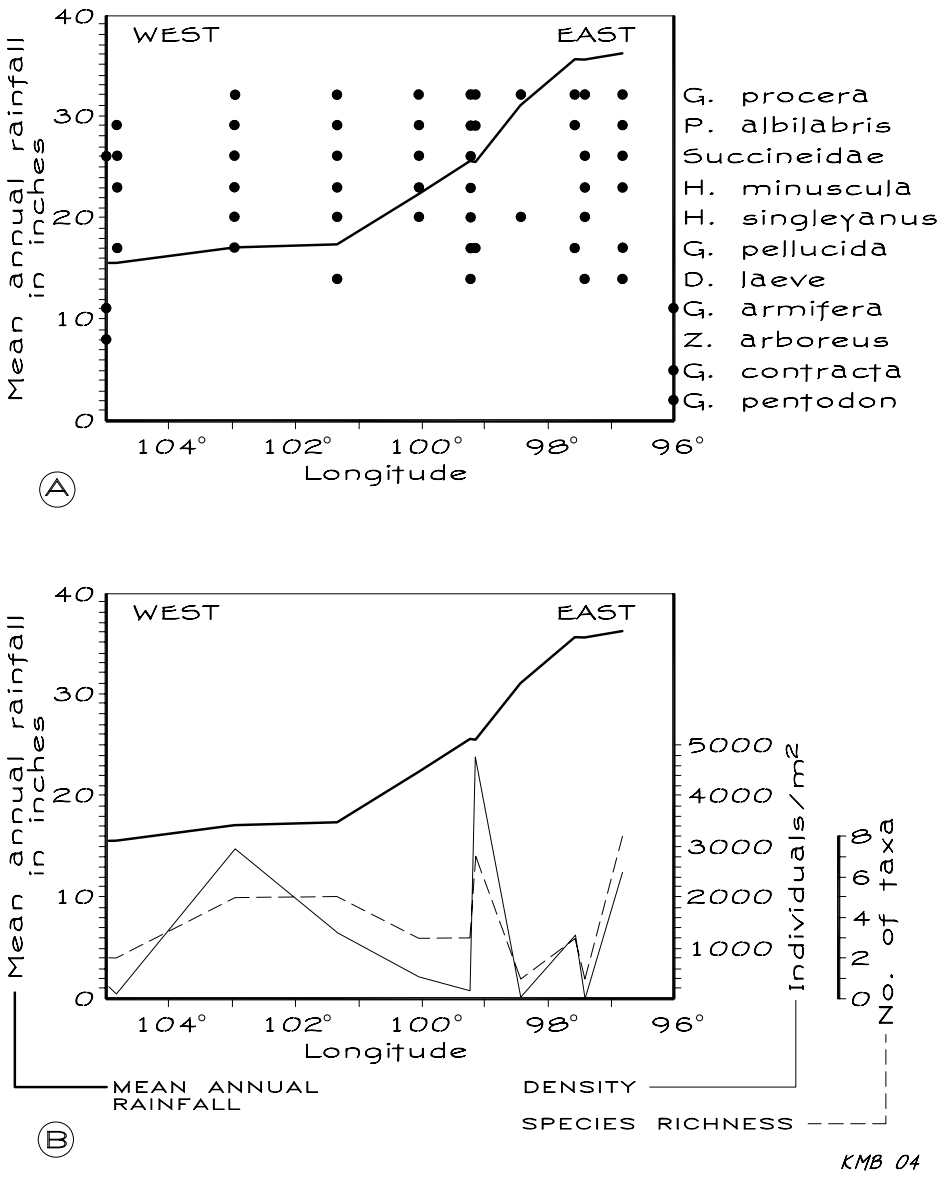


Figure 8.19. The Southern Plains Gastropod Survey. Each panel plots mean annual rainfall (1970-1999 data from Grey House Publishing 2000) for the 11 collecting localities against longitude, running east to west. *A*, presence-absence for 11 categories of mollusks found both in the survey and at Berger Bluff. *B*, mean annual rainfall plotted against species richness and density (number of snails/m^2) for the 11 localities (data from Wyckoff, Theler, and Carter 1997:Table 6). Panel "B" shows there are density and richness "hotspots" embedded in the regional moisture gradient.

TERRESTRIAL SNAILS AS ENVIRONMENTAL PROXIES FOR MOISTURE AND DECIDUOUS TREE COVER

Evans (1972:91) characterizes land snails as follows:

> The ecological niche of most species of land snail is that of small herbivore, scavenger and carrion feeder, living close to the surface of the ground and preyed on, largely one suspects as a subsidiary food source, by birds, hedgehogs, shrews and other small beasts. Most favour the moister and less disturbed habitats of the ecosystem. None appear to be restricted to living on or in association with particular plant species, though the structure of the vegetation is an important factor in their livelihood.

According to Martin, "terrestrial gastropods function primarily in the environment as herbivores, mycophagists (i.e., fungi eaters), and detritivores, although a few snails are carnivorous, feeding on insects, nematodes, earthworms, or other gastropods" (Martin 2000:52).

Which variables control the abundance of live land snails in a given area? What controls their diversity? What controls the proportions of different taxa in a fauna? Evans (1972) devotes an entire chapter to this topic, and Goodfriend (1992:Table 1) also reviews it. Factors most often investigated in the biological literature are moisture, cover (in the form of vegetation, litter, or other objects), food, presence or absence of disturbance, temperature, calcium availability, and pH (Evans 1972: 92-100; Burch and Pearce 1990:201-203; Cain 1983:600-605; Goodfriend 1992:Table 2; Hotopp 2002). In most of Texas, especially South Texas, the latter three factors can largely be disregarded. Except in the quartz sands of east Texas, calcium is usually present in bedrock or pedogenic carbonate, pH is above neutral, and annual temperatures are mild enough not to be a limiting factor for most species.

In Texas, the most important factors for land snails appear to be the highly interrelated variables of moisture, plant cover, and geology. Moisture is necessary for survival of the snails, the plant cover (often deciduous tree litter) they live in, and the litter or fungi they eat. Snails prefer to deposit their eggs in moist soil. Moisture and geology determine whether woodland is primarily deciduous or coniferous. Many snails tend to avoid coniferous woodland, either because conifers tend to grow in calcium-deficient soils, or because conifer needles lack calcium. Some snails are thought to obtain calcium from leaves of deciduous trees (Burch and Pearce 1990:202), so this kind of litter may provide both cover and calcium. Geology determines whether calcium is available from bedrock. Calcium may also come from lichens or mosses, and judging from the geology of the bench deposits (as presented in Chapter 4), it seems plausible that mosses and lichens were abundant when the bench deposits were forming.

Many of the studies that have been done show that soil calcium levels can determine snail abundance and diversity (Burch 1955; Coney et al. 1982; Johannessen and Solhøy 2001; Hotopp 2002) in acid soils where limestone bedrock or pedogenic carbonate are lacking. Others (Riggle 1976) show negative or species-specific responses. Although most of the Berger Bluff catchment is covered by quartz sand soils, there may be enough pedogenic carbonate present to supply calcium needs. Certainly, the abundant phreatic carbonate in the bench sediments was more than adequate for local snail populations, and it seems likely that the combination of abundant moisture and calcium carbonate made the spring-margin area a local “hotspot” for snails.

A number of specialized geographic surveys of land snails have also examined other environmental factors such as exposure to sunlight, topographic position, cliff area (Vollan 2003), elevation or slope, forest succession or stage (Coney *et al*. 1982; Hoff 1962), microtopography (Davies and Grimes 1999), species of tree litter (Getz and Uetz

1994) or cover (Burch 1956), disturbance by fire (Nekola 2002) or forest removal (Ström 2004), magnesium, nitrogen, phosphorus, potassium, and organic carbon content of soil (Burch 1955; Riggle 1976; Nekola and Smith 1999; Ondina *et al*. 2004). None of these appear to be as important for Texas snails as moisture and tree cover.

Careful survey of the biological literature on snails shows that their abundance and taxonomic diversity is actually controlled on two levels:

1) a macroclimatic level: statewide or continent-wide distribution maps show that snails respond to macroclimatic factors;

2) the habitat level: snails respond heavily to favorable microhabitats embedded in regions that may have contrasting humidity, edaphic, or temperature profiles.

In other words, both scales of variation are relevant, regardless of whether we examine contemporary distributions over a large geographic area, or look at changes through time at a single archeological site.

Moisture Requirements

Water loss and recovery are critical for survival of snails and slugs. They lose moisture from the integument and lungs, as well as through the shell and through the mucus trail when moving. Active slugs can lose 30-40% of their body weight within two hours (Prior 1985:403). Snails regulate water loss by adjusting behavior in both time and space. They are nocturnal, they gravitate towards areas with high relative humidity (preferably fully saturated air) or moist substrates, and they are inactive during the day when humidity is lower. During extended dry periods, snails can estivate, practicing metabolic arrest and withdrawing into the shell. Operculate species (like *Oligyra*

orbiculata or *Pomatiopsis lapidaria*) reduce water loss by closing the aperture with the trapdoor-like operculum, while non-operculate species secrete a temporary epiphragm to seal off the aperture (Prior 1985:404-407). Under present climatic conditions, *Rabdotus* may remain dormant for up to 3-4 months at a time during summer and winter (Horne 1973:325). Presumably, reduced seasonality in the Younger Dryas would imply less estivation by most species. Habitat selection is an important strategy for reducing water loss. Land snail surveys large enough to cover several different types of habitats usually reveal that snail species diversity and/or population density increases as habitat moisture increases (see Getz 1974; Boag and Wishart 1982:2635; Bush 1988:856; Martin and Sommer 2004a:201; 2004b:539). Figure 8.20, redrafted from Evans (1972:Fig. 34) shows contemporary snail samples from some sites in northwestern Germany. Both population density (top panel) and species richness (bottom panel) increase somewhat as relative humidity increases. The patterning here, although not strong, is perhaps better defined than in Figure 8.19.

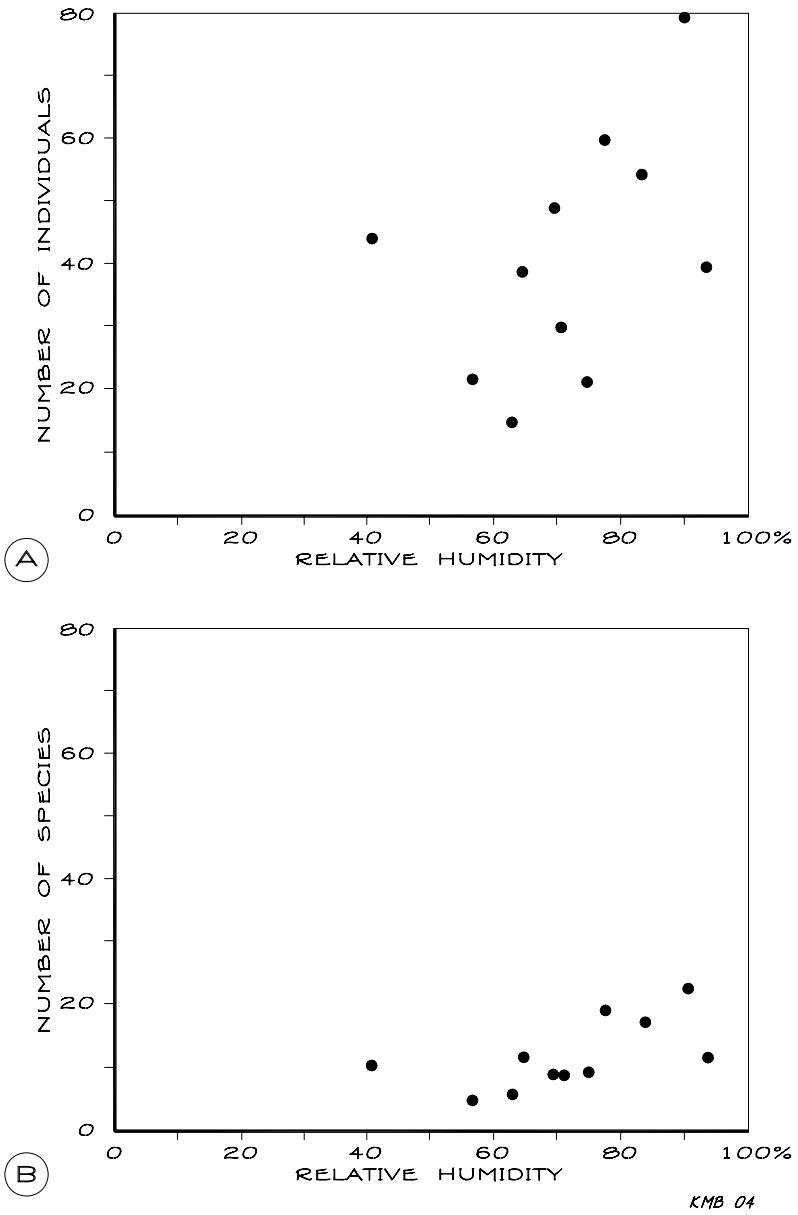


Figure 8.20. Effect of Humidity on Snail Density and Species Richness. *A*, Effect of humidity on population density in 11 contemporary samples from northwestern Germany; *B*, effect on species richness. Both panels are redrafted from Evans (1972:Fig. 34). Patterning is relatively weak, although the scale used in panel B makes it look somewhat stronger.

Although snails are not as abundant in desert biomes as in better watered areas, some species do live in desert areas, and are able to do so by selecting the most sheltered microhabitats and by remaining dormant between infrequent periods of rainfall (Wiesenborn 2003). Except for the amphibious species, land snails also avoid excessive water and actual submersion and will climb to escape excess water (Machin 1975:137). *Rabdotus*, *Oligyra*, *Mesodon* and other species can often be seen clinging to brush well off the ground surface following rains in south Texas. Machin (1975:120) maintains that most water uptake is through the skin, some occurs through food uptake, and whether any occurs by drinking is unknown. According to Cook (2001:468), "drinking" is by contact rehydration through the foot. The largest land snails in the bench deposits were probably capable of traveling no more than a few meters during a night. The home range for the microsnails is unknown, but at most was probably no more than a few centimeters. As a consequence, travel to a point source of water is not usually feasible, so land snails must maintain their water balance by maintaining themselves ins a sufficiently humid microhabitat. Among the largest land snails known are an Australian snail, *Hedleyella falconeri* (up to 9-10 cm in diameter), which moves an average of 8.7 m per night (maximum, about 48 m; Murphy 2002:Table 4) and the giant African snail, *Achatina fulica* which moves 1.5-8.3 m over a two-month period (Tomiyama and Nakane 1993). These give some idea of the upper limit of land snail home ranges. Much more representative, probably is a study by Karson (1999) of movement patterns by *Anguispira alternata*, a close relative of the *Anguispira strongylodes* snails found in the bench deposits. Daily minimum distances traveled averaged about 41 cm, but could be as much as about 3.25 m (Karson 1999:Fig. 12). This is probably fairly representative for the larger-bodied snails in the bench deposits. *Punctum pygmaeum* is a minute land snail with a shell width of about 1.0-1.5 mm and minimum movements of 9.5 cm over a 12-hour period in the wild. Some snails moved as much as about 23 cm in captivity (Baur and

Baur 1988:Fig. 3). This might give a rough indication of home range size for the Berger Bluff microsnails.

The relative size of the snail (both within and among species) has an important effect on its resistance to desiccation. In some cases, juveniles have been shown to have less resistance than adults (Arad and Avivi 1998). Microsnails ought to be especially sensitive to water loss, because as size decreases, the ratio of shell surface area to body volume increases. Barnhart (1989) studied desiccation reactions in pupillid microsnails, including four species present in the bench deposits *(Gastrocopta armifera*, *G. contracta*, *G. procera*, and *Pupoides albilabris*). He found that the mass-specific evaporative water loss varies by a factor of about ten from microsnails to larger-bodied pulmonate snails, and the microsnails are indeed more susceptible to desiccation, but some large bodied species have water loss rates as low as the pupillids he studied (Barnhart 1989:Fig. 2). Some *Gastrocopta armifera* individuals were able to survive as much as nine months at zero relative humidity, though most survived only 2.5 months.

Because microsnails are more susceptible to desiccation, they ought to be especially good indicators of environmental factors such as soil moisture, annual rainfall, and average relative humidity, as mediated by vegetation.

Vegetation and Ground Cover

Although terrestrial snails can be found in habitats ranging from marshland to forest, open grassland, or desert, they are probably most common in woods and grasslands. Perhaps two-thirds of the terrestrial snails found in the bench deposits are commonly found in deciduous woodland. The others are characteristic of more open terrain, ranging from open grassland to chaparral to bare ground (the latter just a couple

of species). Habitat preferences for each species will be listed in the species accounts later in this chapter.

Vegetation is a major determinant of snail abundance and diversity, because vegetation helps to trap moisture, to retard exposure to wind and sun, and to furnish food matter and host fungi for grazing. Land snail surveys large enough to cover several different types of habitats usually reveal that snail abundance and /or species richness are greatest where deciduous tree cover is heaviest (Boag and Wishart 1982:Figs. 1-4; Karlin 1961; Kralka 1986:160; Oughton 1948: 93-94; Vollan 2003:22-23). Getz and Uetz (1994:71) found a positive correlation between snail species diversity and leaf litter diversity. Studies of logging in forest areas show that both snail species diversity and abundance decline after clearcutting (Hylander, Nilsson and Göthner 2004). Rotting logs and downed wood are often important microhabitats for snails (Örstan 1999).

Land snail censuses that include both wooded areas and more open areas (grassland or bare ground) help to illustrate the importance of deciduous woodland. In the Southern Plains Gastropod Survey, the most protected and moist habitats had the highest densities (rock ledges, riparian woodlands, and wooded dunes) and greatest number of taxa (rock ledges, riparian woodlands) of land snails. The least protected and driest sites (dunes, pastures, mesa tops) had the lowest densities and number of taxa (Wyckoff, Theler and Carter 1997:Table 7). A survey in Kansas that encompassed several different kinds of habitats recovered land snails in greatest density in an open prairie wash, a west-facing slope, a hedgerow, and a spring; low densities were found in prairie, stream and pond areas. the highest species richness was found in a wooded area, hedgerow, spring, and limestone ledge; lowest species richness was found around ponds, in prairie, quarry, under a rotten log, and on a south-facing slope (Basch, Bainer and Wilhm 1961:Table III).

In a survey by Logsdon (1967) in Kaufman County, Texas, the greatest land snail species diversity was found on the Trinity River floodplain (Forney site, 20 land snail taxa), in dense grassland with hackberry and elm trees (Reese Farm, 13 taxa), on a creek floodplain with grass, elm and hawthorn (Talty site, 9 taxa), and elm-boxelder-cottonwood woodland (Elmo site, 9 taxa). The lowest species richness was found in areas with ponds (one or no land taxa), and a sparsely vegetated area (Cedarvale site, one species) with some oak and elm trees., as well as semiarid fields and overgrazed floodplains.

Microhabitats

Much of the biological research on land snails shows that microhabitat structure is of key importance in determining presence and density of populations. In other words, from the snail's point of view, it may not make any difference whether the tree canopy overhead is oak or sweetgum, as long as a sufficient thickness of leaf litter is present, and soil moisture retention is adequate. Floristic structure (density and height of cover) may be more important than floristic composition (Labaune and Magnin 2001). Nekola's ordination study of Great Lakes area snails sorted the samples into cliff, upland forest, lowland forest, upland grassland, and lowland grassland groups, but also found that soil surface architecture could predict the species composition of all but 8% of the samples (Nekola 2003:67). Soil architecture consisted of either "duff" (organic horizon over 4 cm thick over a friable A horizon) or "turf" (organic horizon less than 4 cm thick over an A horizon with thick plant roots). In England, Bush (1988) found shade-preferring taxa in grassland, either under small shrubs or on protected slopes, living in what were evidently suitable microhabitats embedded in the more open grassland. Some species may show measurable preferences for leaf litter versus moss, versus rocky talus, versus rotting log microhabitats (Coney *et al*. 1982:90). In Alberta, Platt (1980:21) found that most snails collected in coniferous forest habitats were found near aspen trees or under fallen aspen

logs. In Norway, Vollan (2003:38) found that areas with “calcium-indicating mosses on dry surfaces” had a high species richness and density of land snails.

One of the clearest examples of the importance of microhabitats is the distribution by landform in the Southern Plains Gastropod Survey (Fig. 8.21). Here, the most protected habitat, rocky ledges, yields 15-60 times as many snails as the least protected habitats (mesa tops, pastures, sand dunes; Theler, Wyckoff and Carter 2004:Fig. 2) and the species richness is about 2-3.5 times as high.

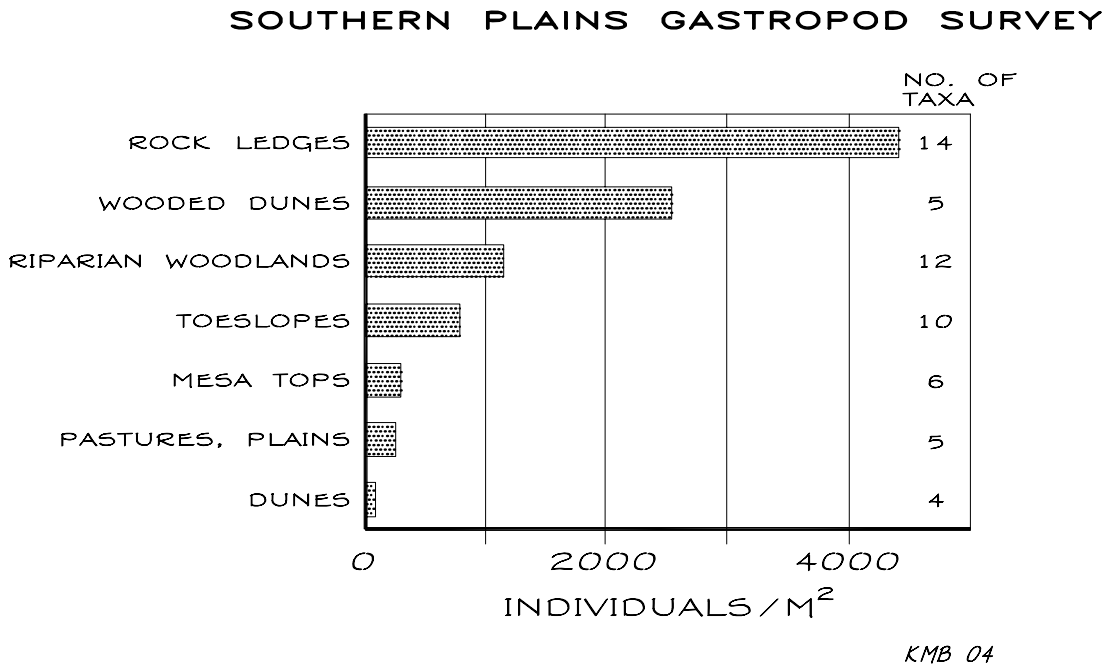


Figure 8.21. Density Variation by Microhabitat in the SPGS. Protected habitats (rock ledges and wooded areas) have higher population density and species richness (adapted from Theler, Wyckoff, and Carter 2004:Fig. 2) of contemporary snails in northern Oklahoma and New Mexico.

SNAILS AS PALEOENVIRONMENTAL DATA

European paleoenvironmental researchers have long used snails as a proxy data source, mostly in England, France, and Poland, employing both biological and stable isotope methods. The principal text (Evans 1972) is by a British archeomalacologist. Table 8.2 lists selected examples of paleoenvironmental studies using snails. The main purpose of the table is show where most of the studies are found and the analytical methods used [a much more comprehensive list for the United States is given by Bogan and Grady (1991:Table 1)]. For the most part, the European studies are much more extensive and sophisticated than those done in the US. The Europeans began to experiment with multivariate ordination methods by at least the 1980s, seeking to extract major paleoenvironmental variables (such as temperature or extent of tree cover) from numerical data matrices, and in some cases, to compute transfer functions for variables such as atmospheric temperature. Rousseau, Limondin and Puissegur (1991) review the major analytical methods that have been applied.

In contrast to the European approach, the chief analytical method applied in most archeological projects in Texas (whether CRM-based or otherwise) is to throw the snails away without studying them, except for a few cases where isotope or epimerization studies are done. Table 8.2 lists some of the major examples in Texas, but the studies listed here represent only a tiny fraction of the archeology that has been done, nearly all of which ignores the potential for archeomalacology. No ordination or transfer function studies have been attempted yet in Texas, although several analyses of epimerization or stable isotopes have been done.

Table 8.2. Selected Examples of Paleoenvironmental Studies Using Snails.

Location	Analyses	Reference
France	diversity index, correspondence analysis	Rousseau, Limondin, and Puissegur (1993)
Western Europe	correspondence analysis, temperature transfer functions	Rousseau (1991)
Western Europe	correspondence analysis, temperature transfer functions	Rousseau *et al*. (1994)
Western Europe	Mutual Climatic Range analysis	Moine *et al*. (2002)
England	species ID, detrended correspondence analysis	Bush (1988)
England	correspondence analysis, temperature transfer functions	Rousseau, Preece, and Limondin-Lozouet (1998)
England	species ID, comparison with other proxies	Meyrick and Preece (2001)
Germany	species ID, comparison with other proxies, mollusk zones, diversity index	Meyrick (2003)
Germany, Luxembourg	species ID, mollusk zones	Meyrick (2001)
Ontario	species ID, mollusk zones	Yang, Yarrow, and Mackie (2001)
Caverne de la Mine, Quebec	species and habitat preference ID, geographic range	Lauriol *et al*. (2003)
New Trout Cave, Hamilton Cave, West Virginia	species ID	Bogan and Grady (1991)
Hall Shelter, Kentucky	species ID, species diversity plot	Bobrowsky and Gatus (1984)
Hayes site, Tennessee	species and habitat preference ID	Klippel and Turner (1991)
22 OK 904, Mississippi	species and habitat preference ID	Peacock and Melsheimer (2003)
Banks site, Iowa	species ID, morphometrics	Baerreis (1971)
Conklin Quarry, Iowa	species and habitat preference ID	Baker *et al*. (1986)
County Line site, Illinois	species and habitat preference ID, epimerization	Miller *et al*. (1994)
Rench site, Illinois	species and habitat preference ID, transfer functions from morphometrics	Rollins (1993)
Cherokee Sewer site, Iowa	species ID, geographic range, transfer functions from morphometrics	Baerreis (1980)

Table 8.2 (continued)

Black Hills, South Dakota	species and habitat preference ID, geographic range	Jass *et. al.* (2002)
Various sites, KS, NE, OK, Texas	species and habitat preference ID	Taylor (1960)
Various sites, Kansas, Nebraska	species and habitat preference ID, geographic range	Wells and Stewart (1987)
North Cove site, Nebraska	species ID	Stewart (1989)
Hudson-Meng site, Nebraska	species and habitat preference ID	Wu and Jones (1978)
Big Hawk Shelter, OK	species and habitat preference ID	Hall (n.d.)
CD 257, Delaware Canyon, OK	species and habitat preference ID, geographic range	Fullington and Fullington (1982a)
Various sites, SW Kansas, NW Oklahoma	species and habitat preference ID, geographic range, transfer functions from morphometrics	Simon (1977), Hibbard and Taylor (1960)
Hajny site, Oklahoma	species and habitat preference ID, geographic range	Branson (1992), Theler (1992)
Burnham site, Oklahoma	species and habitat preference ID, geographic range	Theler (2003a, 2003b)
Domebo site, Oklahoma	species and habitat preference ID, geographic range	Cheatum and Allen (1965)
New Mexico	review of historical biogeography	Metcalf (1997)
Folsom site, New Mexico	^{18}O and ^{13}C isotope analysis of land snails	Balakrishnan *et al*. (2005)
Llano Estacado sites, Texas and New Mexico	species and habitat preference ID	Drake (1975)
Rex Rodgers site, Texas	species and habitat preference ID	Fullington (1978a)
Sulphur Springs site, Texas	species and habitat preference ID	Neck (1994d)
Various sites, Arizona	species ID, comparison to other proxies	Mead (1991)
Lubbock Lake, Texas	species and habitat preference ID, temperature and precipitation estimates from area of sympatry	Pierce (1987)

Table 8.2 (continued)

Lake Theo site, Texas	species and habitat preference ID	Neck (1978, 1987a), Johnson, Holliday and Neck (1982)
Aubrey site	species and habitat preference ID	Neck (2001)
41 DL 270, Texas	species and habitat preference ID	Neck (1994a)
Cooper Reservoir, Texas	species ID	Slaughter (1964)
Bardwell Reservoir, Texas	species ID	Slaughter and Thurmond (1965)
Livingston Reservoir, Texas	species ID	Slaughter (1965)
Various sites, N Texas, Panhandle, OK	species and habitat preference ID	Cheatum and Allen (1963, 1965)
41 MK 38, Texas	species and habitat preference ID	Todd (2002)
Hog Creek sites, Texas	species and habitat preference ID	Kirby and Reeder (1980)
Hoxie Bridge site, Texas	species ID	Bond (1978:208-216)
41 TV 368, Texas	species and habitat preference ID	Neck (1981b)
Kenyon Rockshelter, Texas	species and habitat preference ID	Neck (1986a)
Wilson-Leonard site, Texas	species and habitat preference ID	Shaw *et al*. (1998)
Richard Beene site, Texas	species and habitat preference ID	Neck (1992)
Anthon site, Texas	species and habitat preference ID	Neck (2002)
Swan Lake site, Texas	species and habitat preference ID	Neck (1987c)
Guadalupe Bay site, Texas	species and habitat preference ID	Fullington (2002)
Smith Creek Bridge site, Texas	species and habitat preference ID, qualitative climate inferences from morphometrics	Brown (2002)

Table 8.2 (continued)

Berclair Terrace, Texas	species and habitat preference ID	Conkin and Conkin (1962)
Fordyce Quarry, Texas	species and habitat preference ID	Conkin, Conkin and Mason (1962)
La Paloma Mammoth site, Texas	species and habitat preference ID	Neck (1981a)
Resaca del Rancho Viejo, Texas	species and habitat preference ID	Neck (1985)
Skyline Shelter, Texas	species and habitat preference ID	Neck (1990b)

Note: For many additional examples, see Bogan and Grady (1991:Table 1) and Goodfriend (1992:Table 3).

The French approach to ordination studies is particularly interesting because of a heavy emphasis on atmospheric temperature as the principal variable extracted (Rousseau, Limondin and Puissegur 1993; Rousseau, Limondin, Magnin and Puissegur 1994; Rousseau, Preece and Limondin-Lozouet 1998; Moine *et al*. 2002) despite the fact that many of the contemporary biological studies identify other factors (altitude, microhabitat variation, litter thickness, soil calcium, and so forth) as the most significant variables driving snail abundance and diversity, including at least one study done in France (Labaune and Magnin 2001). There seems to be a major discrepancy between European paleoenvironmental studies (which infer temperature control of variation) and biological studies (which infer a variety of more local factors). The discrepancy might be due to the scale of the calibration data sets used for the paleoenvironmental studies. Rousseau and others (1994) calibrated their study with modern snail analog assemblages collected all the way from Scandinavia to southern France. Using a latitudinal gradient this large, it is not surprising that most of the variation is temperature-related. Most of the biological studies cover smaller areas. Larger-scale studies, like the Southern Plains

Gastropod Survey, or Nekola's (2003) survey of the Great Lakes area, are the exception rather than the rule.

Paleoenvironmental studies that compile calibration data sets covering large geographical areas are an attempt to substitute space for time. Researchers want to know how the abundance of a particular species might vary as temperature changes, so a series of modern snail samples is collected along a north-south temperature gradient that is sufficiently long to show major variation (Rousseau *et al* 1994:Fig. 1; or, in the case of the Southern Plains Gastropod Survey, an east-west moisture gradient). Kadmon and Heller (1998) studied land snails in Israel, an elongated country with a strong north-south rainfall gradient, and as might be expected, the first axis of variation extracted in their ordination study was variation in rainfall. In any case, the scale of the gradient that is used for calibration will affect the results, because different variables become dominant at different scales of inspection.

Except for isotope studies, most paleoenvironmental studies using snails in the US have been qualitative in nature. Snails are identified, inventoried, and assessed for habitat preference, then interpreted qualitatively. There are two kinds of numerical studies that might be attempted. The first consists of ordination studies of large matrices of snail counts, as the Europeans have done, with or without the subsequent computation of climatic transfer functions. The second consists of morphometric studies of selected species over time, with or without the subsequent computation of climatic transfer functions. A small number of these studies have been done in the US, mostly on pupillid species in the Midwest (Baerreis 1971, 1980; Couri 1976; Simon 1977). In Texas, an early attempt was made by Amaral and Witter (1973), who measured *Anguispira* and *Mesomphix* shells from Laneport Reservoir. My own morphometric study of *Rabdotus*, *Praticolella*, and *Polygyra* at the Smith Creek Bridge site (Brown 2002:262-263) was an

attempt to discover if large and medium-bodied snails were sufficiently sensitive to environmental changes to show recognizable fluctuations in body size. In that case, the polygyrids *Praticolella* and *Polygyra* showed some variation over time.

CONTEMPORARY SNAIL POPULATIONS, REGIONAL AND LOCAL

Some kind of baseline knowledge of contemporary populations is essential when evaluating any proxy biotic indicator of past environments. Cheatham and Fullington (1971, 1973), Fullington and Pratt (1974), and Hubricht (1985) map Texas land snail distributions and list some generalized habitat preference data, but provide no data on relative frequencies or distribution across local habitats. Tables 8.3 through 8.9 provide some data that may be helpful in assessing contemporary populations. I have already listed many of these collections in the Smith Creek Bridge site report (see Brown 2002:218-219), but more detail is provided here.

Branson (1967) collected two large river drift samples, on the Brazos River near Columbus and the other at the delta mouth of the Colorado River, presumably near Cedar Bayou. These are drift samples outside of the Guadalupe River basin, so they are not locally relevant, but since Branson lists the counts by species, they provide an opportunity to look at relative frequencies integrated over a large area of the Gulf coastal plain. In Table 8.3 I have simply combined the Brazos and Colorado River counts and ranked them by frequency (a few of the names have changed since 1967, so I list both versions). I am only interested in species known to appear in the Berger Bluff catchment, so 20 additional taxa that he lists are omitted from the table. This table shows not only which Coleto basin species are most abundant on the coastal plain, but also which are most likely to float in water and appear in drift samples. Most of them are land snails. Only five genera (*Biomphalaria, Gyraulus, Planorbella*, *Cincinnatia,* and *Valvata*) are

aquatic, and the last two are listed as extirpated by Fullington (1978b). The *Valvata* specimen is unquestionably an exhumed fossil. The two most abundant taxa, *Gastrocopta contracta* and *Hawaiia minuscula*, are microsnails. There are few large-bodied taxa and they are relatively few in number, perhaps an indication that the large taxa do not flat well. In summary, we can draw three conclusions from this table: 1) large drift samples capture a good representation of taxonomic diversity; 2) most specimens are land, not aquatic snails; 3) drift samples appear to be hydrodynamically biased in favor of micro species and against large-bodied taxa.

Table 8.4 (adapted from Neck 1987b:Table 2) lists live snails found by Raymond Neck near the Smyth Crossing site in Uvalde County, Texas. Again, this sample is not close to the Coleto Creek basin (it is located in a drier part of south Texas), but it illustrates some important points. Snail assemblages are strongly conditioned by habitat. Species richness and snail density are reduced on the exposed gravel bar, and greater in the two vegetated habitats. Ten species are found in the riparian woodland compared to nine in the prairie, and if the large number of *Rabdotus* are omitted, the population would be much larger in the woodland than in the prairie.

Table 8.5 lists taxa collected before 1977 by Raymond Neck from two localities relatively close to the Berger Bluff catchment – Goliad State Park and the Guadalupe River floodplain at the US Highway 59 crossing in Victoria. Neck (1977:65) explicitly notes that none of these are from river drift. All of these species except *Thysanophora hornii* and perhaps *Mesodon roemeri* are present in the bench deposits.

Table 8.3. Contemporary Drift Snails From the Brazos River and Colorado River.

Taxon	Synonomy (Branson 1967)	Adult Body Size	Combined frequency	Rank
Gastrocopta contracta		micro	2477	1
Hawaiia minuscula		micro	627	2
Oligyra orbiculata		med	543	3
Gastrocopta pellucida		micro	242	4
Gastrocopta pentodon		micro	147	5
Polygyra texasiana		med	104	6
Gastrocopta procera		micro	73	7
Rabdotus dealbatus	*Bulimulus dealbatus*	large	40	6
Pupoides albilabris		micro	37	9
Euchemotrema leai	*Stenotrema leai*	med	30	10
Biomphalaria havanensis	*Taphius havanensis*	med	23	11
Zonitoides arboreus		micro	18	12
Helicodiscus singleyanus		micro	18	12
Polygyra mooreana		med	16	13
Praticolella berlandieriana		med	13	14
Mesodon thyroidus		large	11	15
Planorbella trivolvis	*Helisoma trivolvis*	large	5	16
Glyphyalinia umbilicata	*Retinella indentata*	micro	4	17
Mesomphix friabilis		large	4	17
Angusipira strongylodes	*Anguispira alternata*	large	3	18
Vertigo rugulosa		micro	2	19
Gastrocopta tappaniana		micro	2	19
Cincinnatia integra		micro	1	20
Gyraulus parvus		micro	1	20
Valvata tricarinata	(fossil specimen?)	micro	1	20

Source: Branson (1967)

Notes: Frequencies are combined totals for the Brazos River near Columbus and the Colorado River near Matagorda. Only taxa found in the Berger Bluff catchment are listed; 21 other taxa listed by Branson are omitted here. L = large bodied; MD = medium-bodied; MI = microsnail.

Table 8.4. Live Snails from Smyth Crossing, Uvalde County.

Taxon	Gravel bar	Riparian woodland	Savannah/ prairie	Row totals	Rank
Rabdotus mooreanus		3	75	78	1
Gastrocopta pellucida	4	28	14	46	2
Helicodiscus singleyanus	5	11	15	31	3
Polygyra texasiana	2	15	8	25	4
Oligyra orbiculata	2	9	13	24	5
Thysanophora hornii	3	18	2	23	6
Pupoides ablbilabris	3	11	6	20	7
Glyphyalinia umbilicata		9	1	10	8
Succineidae	1	5	3	9	9
Gastrocopta contracta		7		7	10
Number of taxa:	7	10	9		
Number of specimens	27	126	146		

Source: Neck (1987b:Table 2).

Table 8.5. Contemporary Snails From Goliad County and Guadalupe River Floodplain.

Goliad State Park, Goliad County
Anguispira strongylodes
Carychium mexicanum
Catinella vermeta
Euconulus chersinus trochulus
Gastrocopta contracta
Gastrocopta pellucida hordeacella
Gastrocopta pentodon
Glyphyalinia umbilicata
Oligyra orbiculata
Helicodiscus singleyanus
Mesodon roemeri
Mesodon thyroidus
Mesomphix friabilis
Polygyra mooreana
Polygyra texasiana texasiana
Praticolella pachyloma
Pupisoma dioscoricola
Pupoides albilabris
Rabdotus dealbatus
Strobilops texasiana
*Thysanophora hornii**
Zonitoides arboreus

Guadalupe River at US 59, Victoria County
Anguispira strongylodes
Euchemotrema leai aliciae
Gastrocopta pellucida hordeacella
Gastrocopta procera procera
Gastrocopta tappaniana
Glyphyalinia umbilicata

* Not found at Berger Bluff

Source: Neck (1977)

Table 8.6 lists snails collected from the surface at seven localities in the Berger Bluff catchment, while collecting water and soil samples for diatom analysis. All of these were dead shells, except for seven live succineids found on the surface of a damp swale on the first low terrace of Coleto Creek on the Preiss Ranch (locality D-21). Since these specimens were hand-collected, the list is biased in favor of large and medium-bodied species. All of these are terrestrial except the aquatic *Planorbella* and *Biomphalaria* and the amphibious Succineidae.

Table 8.6. Surface-Collected Snails from Diatom Sampling Localities.

D-2, Pool with green algae (DeWitt County)	
Planorbella trivolvis juvenile (?)	1
D-6, Drift from floodplain (DeWitt County)	
Mesodon thyroidus adults	7
Mesodon sp. juveniles	7
Oligyra orbiculata adults	7
Oligyra orbiculata juvenile	1
Rabdotus cf. *R. dealbatus* adults	10
Rabdotus sp. juveniles	5
Succineidae	2
Biomphalaria obstructa	1
D-9, Floodplain north of crossing (DeWitt County)	
Rabdotus cf. *R. dealbatus* adult	1
Rabdotus sp. juveniles	2
Praticolella cf. *P. pachyloma* adults	4
Praticolella sp. juveniles	3
D-19, Northwest bank of creek (DeWitt County)	
Mesodon thyroidus adult	1
Mesodon sp. juvenile	1
Rabdotus cf. *R. dealbatus* adults	2
Rabdotus sp. juveniles	2
Helisoma anceps juveniles	2
D-21, Downed wood in live oak mott (Goliad County)	
Strobilops texasiana juvenile	1
Helicodiscus singleyanus adults	2
Helicodiscus singleyanus juveniles	3
?Gastrocopta pellucida juvenile	1
D-21 Vicinity, prickly pear patch (Goliad County)	
Mesodon thyroidus adult	1
Oligyra orbiculata adults	5
Polygyra texasiana adult	1
Helicodiscus singleyanus	1
Succineidae	1
D-21 Vicinity, swale on floodplain (Goliad County)	
Oligyra orbiculata adult	1
Succineidae (live)	7

Note: Identification by K. Brown.

CONTEMPORARY SNAIL SAMPLES FROM THE PREISS RANCH

On November 18, 1998, in conjunction with diatom sampling, Cecil Calhoun and I collected some contemporary snail samples from the Preiss Ranch, about 10.5 km northwest of and upstream from Berger Bluff. The area is on the south side of Coleto Creek, west of Arnold Road, and the geology is discussed in Chapter 4 (see Fig. 4.5 for a map of the area). Two localities were sampled with excavated 50 x 50 cm quadrats. The procedure is essentially the same as that used for the Southern Plains Gastropod Survey, except that only one quadrat was collected at each locality, instead of three replicates. All of the snail identifications here are my own.

Locality D-20 (UTM coordinates Zone 14, E6 72 080, N31 94 030) is on the sandy lower post-Beaumont terrace, 3.75 m above the creek at about 125 feet. The quadrat was laid out inside a small live oak mott about 10 x 35 m in size (see Fig. 4.18 for a photo). The surface was sandy and mostly free of vegetation under the oak canopy except for scattered dewberry, yaupon, live oak seedlings, poison ivy, bull nettle, *Ipomea* sp. (?), and mustang grapevines. The terrace surface had been briefly overtopped by the floods of November 13-15, Octobers 18-20, and possibly October 6-7, 1998. Outside the canopy but adjacent, prickly pear, scarlet sage, tasajillo, mesquite seedlings, and ragweed were present, with some thin Bermuda grass cover on the nearby slope. The ranch is actively grazed by cattle. Two levels were collected from the quadrat. Level 2 (2-4 cm) was collected but has not been processed. Level 1 (0-2 cm) included very little surface leaf litter and consisted of 2.0 liters of sand (4.64 kg dry weight) sieved through #8 and #35 mesh geologic sieves. The results are shown in Table 8.7. Large numbers of *Gastrocopta pellucida* (129) and *Helicodiscus singleyanus* (85), along with nine *Gastrocopta contracta*, a single *Rabdotus*, and an aquatic snail were recovered.

Table 8.7. Snails From 50-cm Quadrats on the Preiss Ranch.

Taxon	#8 mesh	#10 mesh + floated	#18 mesh	#25 mesh	#35 mesh	Row total
D-20, 50 cm quadrat, level 1 (Lower post-Beaumont terrace) 2.0 liters, 4.64 kg dry wt						
Gastrocopta pellucida adults	36				83	119
Gastrocopta pellucida juveniles	7				3	10
Gastrocopta contracta adults	2				7	9
Gastrocopta sp. juveniles	0				22	22
Helicodiscus singleyanus adults	11				39	50
Helicodiscus singleyanus juveniles	9				26	35
cf. *Rabdotus dealbatus* juvenile	1				0	1
Planorbidae, unidentified	1				0	1
Unidentified juveniles	2				4	6
D-21, 50 cm quadrat, level 1 [Beaumont (?) terrace] 4.20 liters, 4.47 kg dry wt						
Gastrocopta pellucida adults		0		4	0	4
Gastrocopta sp. fragments		0		2	0	2
Strobilops texasiana juvenile		0		1	0	1
cf. *Vertigo rugulosa* (?)		0		1	0	1
Unidentified fragments		0		1	0	1

Notes: #8 and #35 mesh only used for D-20; floated material combined with #10 used for D-21, along with #25 and #35 mesh; floated material, #10 and #35 were barren of snails. Identification by K. Brown.

Locality D-21 (UTM coordinates Zone 14, E6 72 370, N31 93 780) is on the sandy Beaumont (?) terrace roughly 330 m away from the creek. This locality is inside a much larger, more mature live oak mott with closed, well-shaded canopy, dense leaf litter on the ground, and moderately abundant downed wood (see Fig. 4.17 for a photo). There is fairly heavy ground cover, mostly frostweed in some areas, but also ragweed, coral bean, French mulberry, hackberry, tasajillo, huisache, yaupon, cowpen daisy, poison ivy, sunflower, scarlet sage, and huisache daisy. A single 50 x 50 cm quadrat was excavated here about 70 cm from the base of a large live oak tree. Two levels were collected from the quadrat. Level 2 (2-4 cm) was collected but has not been processed. Level 1 (0-2 cm) consisted of 4.2 liters of sand (4.47 kg dry weight) with very abundant leaf litter. It was sieved through #10, #25, and #35 mesh sieves. Any snails that floated

during processing were combined with the #10 mesh sample. The results are shown in Table 8.7. Because this locality is so heavily vegetated and leaf litter is thick, an abundant snail population was expected, but instead, this quadrat proved to be nearly sterile, producing only a few *Gastrocopta pellucida*, a *Strobilops texasiana*, and a single snail tentatively identified as *Vertigo rugulosa* (?). The low snail density in this protected locality remains unexplained. The mott serves as a shade refuge for cattle, so possibly cattle disturbance is related in some way.

About 700 g of downed live oak wood was collected off the surface, bagged, and later rinsed in the lab to extract microsnails. The results are shown in Table 8.6. Only a few *Helicodiscus singleyanus* and single specimens of *Strobilops texasiana* and *Gastrocopta pellucida* were recovered. Downslope and several meters north from locality D-21, a small grab sample of mostly large and medium-sized snails (*Oligyra*, *Mesodon*, *Polygyra*, *Helicodiscus*, and a succineid) was collected from an exposed prickly pear patch and is listed in Table 8.6.

One additional collection was made from a drift sample found on the south bank of Coleto Creek, due north of locality D-21. The location is marked as “DS” for “drift sample” on Fig. 4.5. This flood deposit of leaves, woody debris and snail shells was probably left by the waning floodwaters of November 13-15, 1998 and was bagged in its entirety and returned to the lab for processing. Careful hand picking produced over a thousand specimens, of which over 95% are terrestrial. The results are shown in Table 8.8, and in Table 8.9, I have re-ordered the same data by abundance rank. These two tables, along with Table 8.7, seem to offer a fair picture of the contemporary snails in the catchment. *Gastrocopta pellucida* is the most abundant species, followed by *Helicodiscus singleyanus* (adults and juveniles combined). These two species are hardy, drought-tolerant, cosmopolitan species that can persist in well-drained sandy pasture subject to

severe summer drying. *Gastrocopta contracta,* a more mesic-adapted species, is much less abundant. In the drift sample, the *contracta/pellucida* ratio is about 1:2, and in the excavated quadrats, it is less than 1:14. Later in this chapter, I will suggest that the *contracta/pellucida* ratio is a useful measure of prevailing soil moisture, and will show that the ratio is very different in the bench deposits. Somewhat over half the individuals in the drift deposit are member of fairly drought-resistant, stenotopic species (*G. pellucida*, *G. pentodon*, *H singleyanus*, *Oligyra orbiculata*, *Pupoides albilabris*), often characteristic of open, sparsely wooded or grassy areas. These may have come from grassy slopes adjacent to the creek or from open, grassy floodplain surfaces. Less than half the individuals come from species (*Gastrocopta contracta*, *Carychium mexicanum*, *Strobilops texasiana*, *?Vertigo rugulosa*, *Polygyra cereolus*, *Euconulus* sp.) more characteristic of wooded floodplains or more mesic habitats. Except for the aquatic snails, this is a somewhat more drought-adapted assemblage than is seen in the bench deposits.

The drift sample includes at least 20 taxa of land snails (possibly more, since some are unidentified) and at least seven of aquatic snails. Some of these deserve comment, either because the identifications are tentative or because they have not been previously reported from Goliad County. There are 49 specimens from the drift sample and one from locality D-21 tentatively identified as *Vertigo rugulosa.* This is an uncommon species, poorly mapped in Texas and not documented as occurring any closer than Lavaca County and Jackson County (Cheatum and Fullington 1973:Fig. 11). This is a tentative identification, previously unreported for Goliad County. *Polygyra auriformis* is not reported from Goliad County, but is present in Victoria County and Gonzales County (Cheatum and Fullington 1971:Fig. 6). *Polygyra cereolus*, also previously unreported in Goliad County, is synonymous with *Polygyra septemvolva* and is typically a tropical coastal resident (Pratt 1981:Fig. 11), perhaps a recent invader. *Helicodiscus eigenmanni* is unreported from Goliad County but occurs in the Edwards Plateau area

(Hubricht 1985:Map 180). The three specimens found here are larger than typical *H. singleyanus*.

Fullington (1978:20, 37) says that all known records of *Cincinnatia integra* (synonymous with *C. cincinnatiensis*) in Texas are fossils, but expressed the opinion that living colonies might be found in northeastern or central Texas. That seven specimens were found in the drift sample may indicate a living population somewhere in the Berger Bluff catchment. It seems unlikely as many as seven fossils would be present in a single modern drift sample. Branson (1967:299) also found one in his Colorado River drift sample. One specimen resembling *Micromenetus dilatatus* is present, but the identification is tentative. Another small striated planorbid is unidentified; it resembles some species of *Drepanotrema*, such as *Drepanotrema aeruginosum* (?).

Among the commented species (*V. rugulosa, P. auriformis, P. cereolus, H. eigenmanni, M. dilatatus,* the possible *Drepanotrema,* and *C. integra*), only *C. integra* is found in the bench deposits.

Among the (approximately) 27 taxa in the drift deposit, only one aquatic snail (*Helisoma anceps*) might be considered large-bodied, while seven land or amphibious species are medium–bodied, and the rest are microsnails. All of the major large-bodied genera found in the bench deposits (*Anguispira, Mesomphix, Mesodon, Rabdotus, Planorbella*) are absent from this drift deposit, either because of hydrodynamic bias or some other reason. Very small genera like *Helicodiscus* or any of the *Gastrocopta* will often float if the shell is empty, because surface tension bars water from entering the shell. Larger species tend to fill with sediment or water, though I have seen abundant *Anguispira strongylodes* in Brazos River drift. *Mesodon* and *Rabdotus* shells were found on floodplains elsewhere in the catchment (Table 8.6), but no *Anguispira* or *Mesomphix*.

Table 8.8. Contemporary Snails from Coleto Creek Drift Sample, Preiss Ranch.

Terrestrial taxa	**Count**	**Aquatic taxa**	**Count**
Carychium mexicanum adults	59	*Biomphalaria obstructa*	22
Euchemotrema leai adult	1	*Cincinnatia integra*	7
Euconulus sp. [1]	11	*Helisoma anceps*	1
Gastrocopta contracta adults	96	Lymnaeidae, unident. juveniles	7
Gastrocopta pellucida adults	201	cf. *Micromenetus dilatatus*	1
Gastrocopta pentodon adults	28	*Physella virgata* juveniles	8
Gastrocopta procera adults	13	Planorbidae, juvenile	1
Gastrocopta spp., unidentified	33	Planorbidae, unident. striated [8]	1
Glyphyalinia umbilicata	8	AQUATIC SUBTOTAL:	48
Helicodiscus eigenmanni [2]	3	GRAND TOTAL:	1013
Helicodiscus singleyanus adults	98		
Helicodiscus singleyanus juveniles	74	Terrestrial percent:	95.26
Oligyra orbiculata adults	36	Aquatic percent:	4.74
Oligyra orbiculata juveniles	11		
Polygyra auriformis adult	1		
Polygyra cereolus	14		
Polygyra texasiana adults	29		
Polygyra sp. adults [3]	4		
Polygyra sp. juveniles	30		
Praticolella cf. *P. pachyloma* adults	1		
Pupoides albilabris adults	10		
Strobilops texasiana adults	38		
Strobilops texasiana juveniles	20	Other aquatic fauna	
Succineidae	12	*Corbicula fluminea*, paired	64
cf. *Vertigo rugulosa* [4]	49	*Corbicula fluminea*, single	24
Zonitoides arboreus	1	Ostracods, paired valves	8
conical-discoidal juveniles [5]	29	Ostracods, single valves	11
discoidal juveniles [6]	8		
spiral juveniles [7]	47		
TERRESTRIAL SUBTOTAL:	965		

Notes: Drift sample collected from south bank of Coleto Creek on Preiss Ranch, north of diatom locality D-21, November 18, 1998. Identification by K. Brown.

[1] Resembles *Euconulus trochulus*; largest is 2.7 mm in diameter.
[2] Larger than *H. singleyanus* (3.6, 3.4, 3.0 mm diam.), faint horizontal ridges, deep interior teeth.

(Notes continued on following page)

(Table 8.8 notes continued from previous page)

[3] Possible *P. cereolus* X *P. texasiana* hybrid? Aperture resembles *P. cereolus*, but shell is domed like *P. texasiana*.
[4] Not previously reported in Goliad County. Most appear slightly subadult, less than 2 mm height.
[5] No umbilicus (juvenile *Oligyra* or *Polygyra*, cannot discriminate).
[6] Presumably juvenile *Glyphyalinia*, *Mesomphix*, or similar taxa.
[7] No umbilicus; these resemble *Gastrocopta* sp. juveniles.
[8] Resembles *Drepanotrema aeruginosum*?

Table 8.9. Coleto Creek Drift Sample Ranked by Abundance.

Taxon (or category)	**Count**	**Rank**
Gastrocopta pellucida adults	201	1
Helicodiscus singleyanus adults	98	2
Gastrocopta contracta adults	96	3
Helicodiscus singleyanus juveniles	74	4
Carychium mexicanum adults	59	5
cf. *Vertigo rugulosa*	49	6
spiral juveniles	47	7
Strobilops texasiana adults	38	8
Oligyra orbiculata adults	36	9
Gastrocopta spp., unidentified	33	10
Polygyra sp. juveniles	30	11
conical-discoidal juveniles	29	12
Polygyra texasiana adults	29	12
Gastrocopta pentodon adults	28	13
Biomphalaria obstructa	22	14
Strobilops texasiana juveniles	20	15
Polygyra cereolus	14	16
Gastrocopta procera adults	13	17
Succineidae	12	18
Euconulus sp.	11	19
Oligyra orbiculata juveniles	11	19
Pupoides albilabris adults	10	20
discoidal juveniles	8	21
Glyphyalinia umbilicata	8	21
Physella virgata juveniles	8	21
Cincinnatia integra	7	22
Lymnaeidae, unident. juveniles	7	22
Polygyra sp. adults	4	23
Helicodiscus eigenmanni	3	24
cf. *Micromenetus dilatatus*	1	25
Euchemotrema leai adult	1	25
Helisoma anceps	1	25
Planorbidae, juvenile	1	25
Planorbidae, unident. striated	1	25
Polygyra auriformis adult	1	25
Praticolella cf. *P. pachyloma* adults	1	25
Zonitoides arboreus	1	25

Note: Data from Table 8.6, reordered by abundance.

SNAILS FROM THE BENCH DEPOSITS AT BERGER BLUFF

Kinds of Samples

There are three kinds of samples of snails from the bench deposits:

1) Snails from the quarter-inch screen. All snails retained on the quarter-inch dry screen were saved from six excavation units. In two other units, Unit 2 and N113 E98, snails were not saved. Because dry screening resulted in significant shell breakage (especially in the more heavily cemented lower levels) and loss of juveniles and microsnails, this sampling method produced a partial, but fairly good sample of almost 9000 large and medium-bodied snails, inventoried and identified in 1996 and 2003 by K. Brown. The principal value of these samples is to provide a more extensive quantitative picture of the large species than can be obtained from small matrix samples. Over 600 microsnails and three sphaeriid clams were also recovered from sediment lodged in the apertures of (or adhering to the outside of) larger species. These, termed "fortuitously recovered microsnails," cannot be considered an unbiased sample of the micro-sized species, but they have also been inventoried and represent an additional source of useful information.

2) Snails from two matrix columns. Columns of matrix samples from two units, N109 E103 and N110 E102, were washed through fine-mesh geologic sieves to obtain a representative sample of all body sizes. Processing of about 138 kg of sediment representing 47 samples yielded 4905 snails and two sphaeriid clams altogether, identified in 1982 by Raymond Neck. Because of the processing method, this is the most unbiased sample of species available, although the sample volume is obviously not as large as in the other two methods. Microsnails and large and medium-bodied adults and juveniles were recovered. Snails that floated to the surface during processing were

tabulated separately, in order to check whether any taxa were especially prone to fluvial deposition.

3) Snails from bulk matrix passing the quarter-inch screen in N109 E96. All dry matrix passing the quarter-inch screen in this unit was bagged in bulk and later washed through fine-mesh screens at the Vertebrate Paleontology lab, primarily to check for microvertebrate remains. The screen residue was stored in the lab, and selected levels were later picked. This recovery method produced large numbers of microsnails and juveniles from larger species, but because the picking and identification process is so time and labor-intensive, few levels have been picked. Analytically combined with the quarter-inch sample from N109 E96, these levels have the (mostly unrealized) potential to yield very large, relatively unbiased samples of all species and age groups. Fine mesh samples tend to capture the embryos and juveniles that are missed in the 1/4-inch sample, but because juveniles often cannot be identified very specifically, fine mesh samples may actually tend to produce a higher proportion of unidentified specimens.

Snail Shell Taphonomy and Identification

Several factors potentially can influence the numerical composition of archeological snail assemblages:

1) differential preservation of shells
2) differential identifiability of taxa
3) differential buoyancy of shells deposited by flooding
4) variation in diligence of screeners recovering snails from 1/4-inch screen
5) differential reproductive rates of different species

Shell architecture (for example, the strength of the bonds between the whorls) and compactness (overall size in relation to wall thickness) of the shell are the chief factors determining whether a shell will survive chemical decay, bioturbation, and the archeological recovery process. Survival, in this case, means preservation of enough of the shell to ensure it is not counted more than once.

Identifiability of the bench species varies considerably. Some taxa, like *Anguispira strongylodes* or *Oligyra orbiculata* can be reliably identified even from small fragments of shell, based on distinctive texture or shape, and both of these taxa are monotypic as well, so there is little likelihood of a misidentification. At the other extreme are many of the microsnails (such as the various *Gastrocopta* species) which usually cannot be identified unless nearly all the shell is present. The difficulty of identification also varies widely. Many of the discoidal shells (both land and aquatic taxa) are hard to discriminate (for example, *Helicodiscus singleyanus* and *Hawaiia minuscula*, or *Planorbella trivolvis* and *Helisoma anceps*). In some cases, species that are morphologically convergent have similar habitat preferences, so the analytical penalty for making a wrong identification is not severe. Some of the individual taxa deserve comment, as follows.

1) Small, compact shells in the genera *Oligyra*, *Polygyra*, *Euchemotrema*, and *Strobilops* have survived best and may be slightly overrepresented.

2) *Anguispira* shells tend to survive well (the exterior ridging adds strength) and are readily identifiable, but the basal whorl is usually broken away at the aperture, so that diameter measurements represent a minimum diameter only. Many shells even retain their orange tiger banding, and this is the only species in the bench deposits to retain any of its original coloration. Perhaps because of shell strength, juveniles are better

represented than in most other species, and even embryonic *Anguispira* are present in some quantity in various levels.

3) *Rabdotus* shells are rarely found intact in the bench deposits (the more robust *Rabdotus alternatus* found at the Smith Creek Bridge site are either rare or absent here), but sometimes enough of the basal part remains to allow measurement of the aperture height. Adults and juveniles may be somewhat underrepresented in the counts. The number of *Rabdotus* intact enough for measurement is remarkably small, compared to the Smith Creek Bridge site.

4) Survival of *Mesomphix* shells is poorest because the whorls are poorly joined (the species name *friabilis* is descriptive), and the species is underrepresented. The shell is rather thick-walled, but the joints are so weak that fragments survive much better than complete shells.

5) Survival of *Mesodon* shells is similar to that of *Mesomphix*, or even worse. Very few intact or measurable specimens were found in the bench deposits, but wall fragments can be identified on the basis of very fine raised ridges, much finer than those seen on *Anguispira*. Tentatively, two species of *Mesodon* are thought to be present, but the scarcity of complete specimens obscures this issue.

6) Some genera (most notably *Praticolella* and *Mesodon*) have spires that collapse easily, making height measurements impossible. This, in turn, may make it impossible to assign the specimen to species. Many of the *Rabdotus* shells from the bench also have the spires snapped off, making height measurements impossible.

7) There are also survivorship differences among the microsnails. Compact species like *Strobilops* seem to be resistant to destruction. Among the species of *Gastrocopta*, *G. contracta*, which is short and wide with a well-developed reflected lip at the aperture, seems to be more durable than *G. pellucida*, which is slender and more delicate.

8) Slug plates are perhaps the most durable of all the shells in the deposits, but are so difficult to recognize in sorting that they are probably the most underrepresented element in the entire assemblage. Slug plates resemble nothing more than small fractured quartz pebbles, and are very easy to overlook. Only two slug plates have been found in the bench deposits, but I suspect they are far more common and have simply been missed in sorting.

Figures 8.22 and 8.23 show the stratigraphic distribution of large and medium-bodied snails (adults and juveniles) from the 1/4-inch screen in six excavation units. Fortuitously recovered microsnails are omitted from these plots, and the histograms show density (number of individuals per cubic meter of fill) in order to accommodate the odd-sized excavation levels at the top of most of the excavation units. These histograms show that snails are abundant in the uppermost strata (particularly strata 3 and 2D, where they number over 9000 specimens per cubic meter in one unit), but decline precipitously in abundance with depth. In all the units, the counts diminish dramatically below the base of stratum 2C.

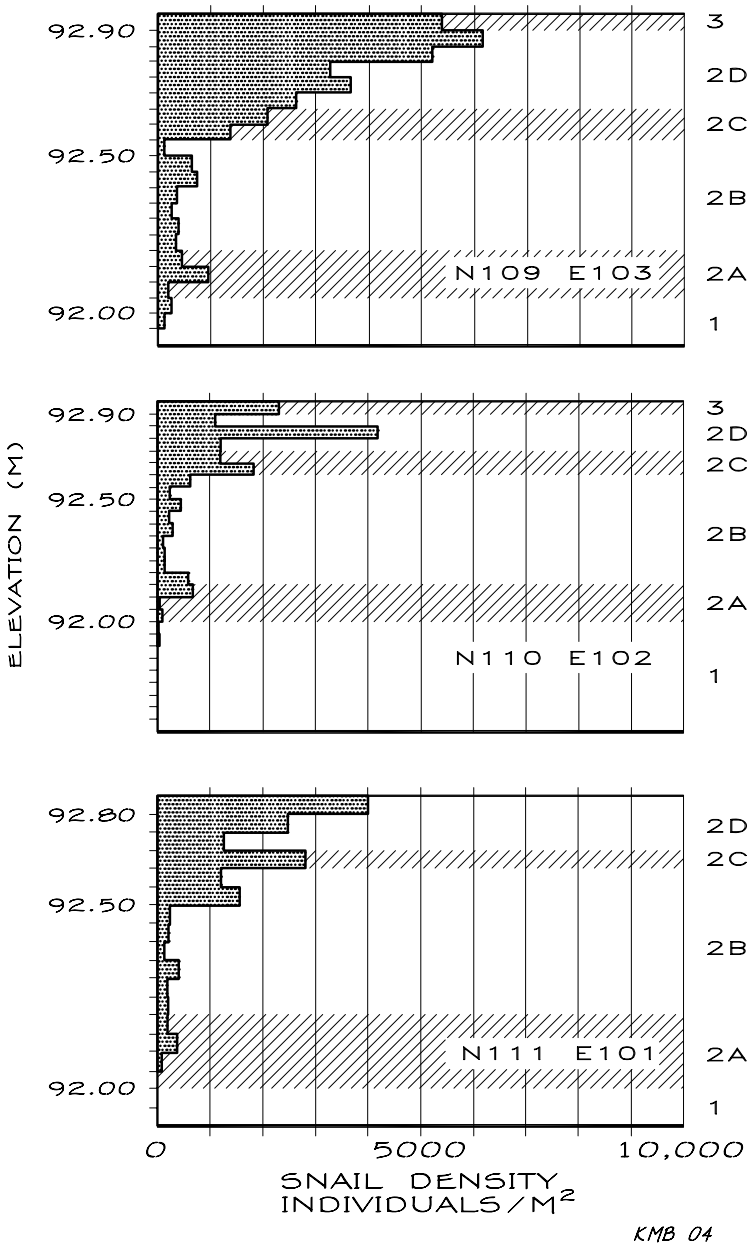


Figure 8.22. Density of Snails Recovered From Quarter-Inch Screen, Eastern Three Units. Snail density (counts of individuals per cubic meter, not including microsnails) is plotted by excavation level in the three easternmost excavation units. Note reduction in density below stratum 2C.

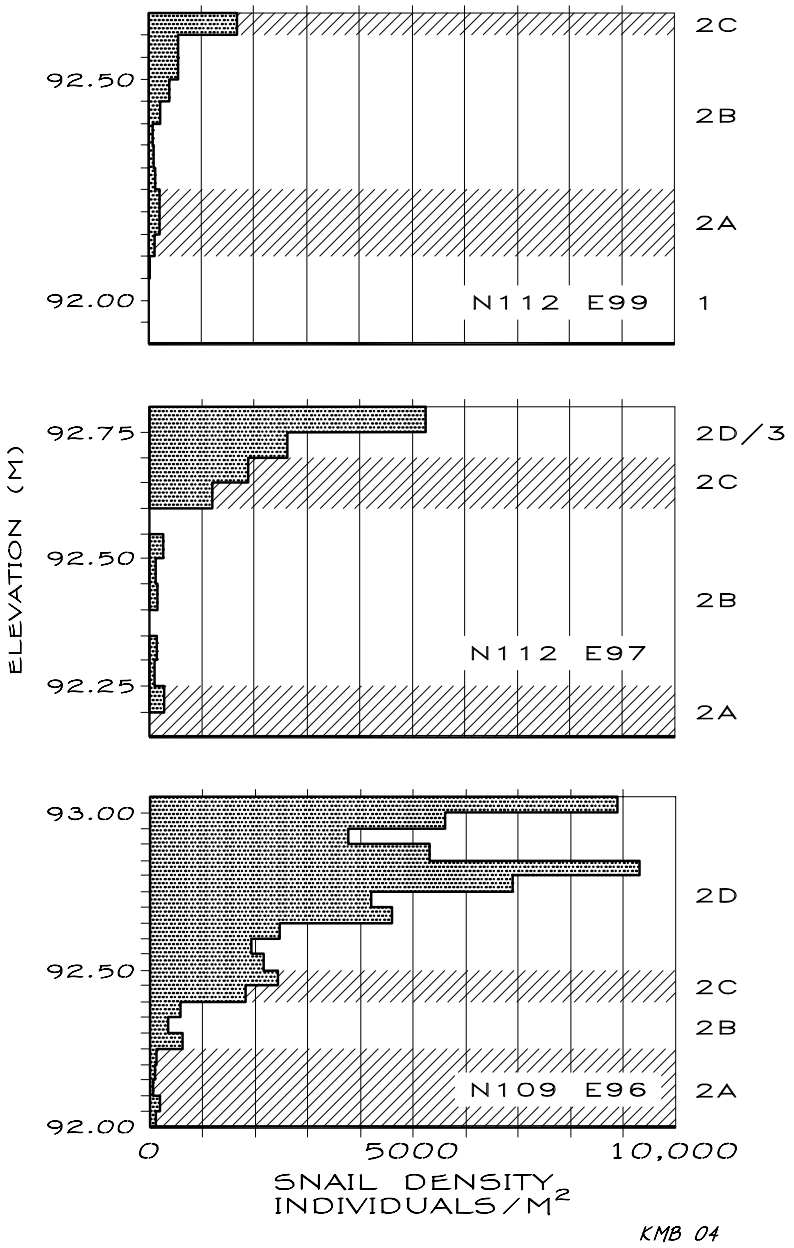


Figure 8.23. Density of Snails Recovered From Quarter-Inch Screen, Western Three Units. Snail density (counts of individuals per cubic meter, not including microsnails) is plotted by excavation level in the three westernmost excavation units. Note reduction in density below stratum 2C.

This vertical pattern is exactly opposite to that that displayed by the diatoms. In the single column of samples (from N110 E102) analyzed, diatoms become more abundant and diverse with depth. As a result of this distribution, paleoenvironmental information from snails is biased toward the upper half of the bench deposits.

There are four possible explanations for the observed vertical distribution:

1) *Snail populations expanded late in the history of the bench deposits*. This seems unlikely, since other data from the site suggests the environment was becoming drier and subject to more frequent flooding late in the history of the bench.

2) *Declining sedimentation rates allowed more shells to accumulate at the top of the bench*. This also seems unlikely. As discussed in Chapter 4, there may have been long-term changes in sedimentation rates, but there is no unambiguous evidence for it. Sedimentation rates were perhaps slightly higher in stratum 1, and possibly in some of the other sandy units, but there is no reason to assume a dramatic slowing of sedimentation at the top of the bench. Resolution of the radiocarbon assays is to poor to clarify this issue.

3) *Chemical decay has removed shells from the lower deposits*. Chemical dissolution and removal in the lower strata is very likely. In Unit N112 E97, shells in the 92.45-92.40 m level and below show thinning and weakening of the shell wall and heavier exterior carbonate deposits. In some cases, heavy, dense carbonate deposition inside shells has formed a steinkern inside the shell, fragmenting the wall and forcing the fragments apart with expansion.

4) *More thorough cementation of the lower strata has caused increased breakage of shells recovered from the 1/4-inch screen*. In the carbonate-cemented lower levels of the bench deposits, heavy working of the fill was necessary during field dry-screening in order to force it though the 1/4-inch screen, resulting in severe breakage of snails shells. This is probably the single most important factor responsible for reduced snail counts in the lower strata.

Figures 8.24 and 8.25 show the same data as the top two panels in Figure 8.22, but plotted as curves rather than histograms. The heavy solid curve is for large and medium-bodied snails from the quarter-inch screen. Also shown, as a dashed line, is the curve for snail density in the snail matrix columns (all body sizes, from microsnails to large-bodied species) for the two units where snails from small matrix samples. These two figures illustrate the effect that recovery method has on snail counts. In both Figure 8.24 and Figure 8.25, snail density is higher in the matrix columns than on the dry screen, at least in the lower strata, but density fluctuations are more or less synchronized. In the upper parts of both excavation units (indicated by the brackets) the two density measures become desynchronized, and the curves cross toward the top of each plot.

Examination of these two plots suggests not only that factor 4 listed above (dry screen breakage) is a major contributor to the decline in snail counts, but some environmental factor causing decoupling of microsnail and large/medium snail population sizes may have become active later in the history of the bench deposits (in upper stratum 2B and above).

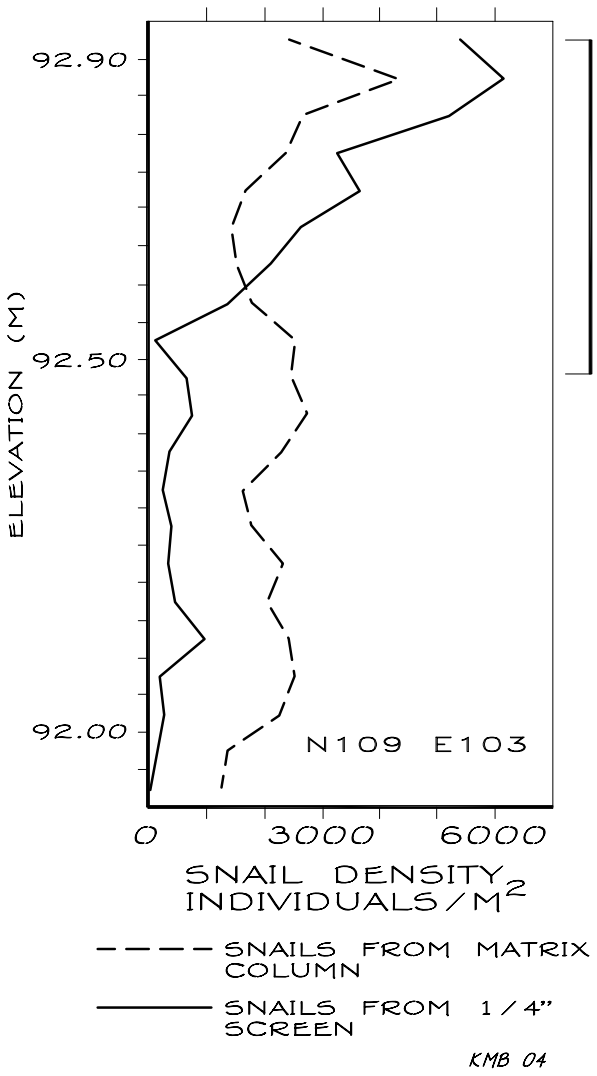


Figure 8.24. Coarse and Fine Mesh Recovery Compared for Unit N109 E103. Solid line shows density of large and medium-bodied snails from the ¼-inch screen (fortuitously recovered microsnails are not included here); dashed line shows density of all body sizes from matrix samples wet-sieved through fine mesh. Bracketed area indicates where the two recovery methods become desynchronized.

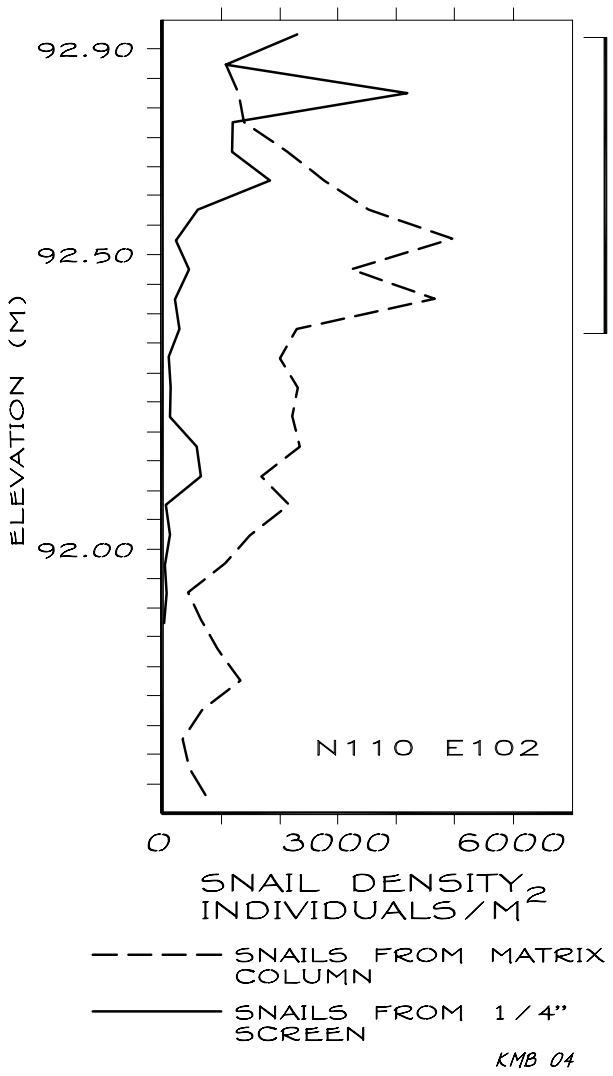


Figure 8.25. Coarse and Fine Mesh Recovery Compared for Unit N110 E102. Solid line shows density of large and medium-bodied snails from the ¼-inch screen (fortuitously recovered microsnails are not included here); dashed line shows density of all body sizes from matrix samples wet-sieved through fine mesh. Bracketed area indicates where the two recovery methods become desynchronized.

Figure 8.26 was compiled in order to discover whether unequal shell breakage and loss in the lower part of the bench deposits has affected the composition of the large and medium-bodied assemblage from the 1/4-inch screen. Data from all excavation units except Unit 2 and N113 E98 are aggregated. The upper pie chart shows the percentage composition for strata 2D and 3 combined, while the lower one shows strata 1 and 2A combined. Counts from stratum 2B, which is intermediate in preservation characteristics, and counts of microsnails are omitted. Only the most abundant taxa are labeled for clarity. These two pie charts show that the most durable species tend to dominate both, but the two are not as different as might be expected. The principal difference between the two is that *Anguispira strongylodes*, the most abundant species in strata 1 and 2A, retreats to fifth rank in the upper pie chart. This may be due partly to taphonomic considerations, but it also may be largely due to habitat change. In general, these diagrams suggest shell decay and loss has biased the earlier part of the record less than I would have expected, given the severe reduction in counts toward the base of the bench deposits.

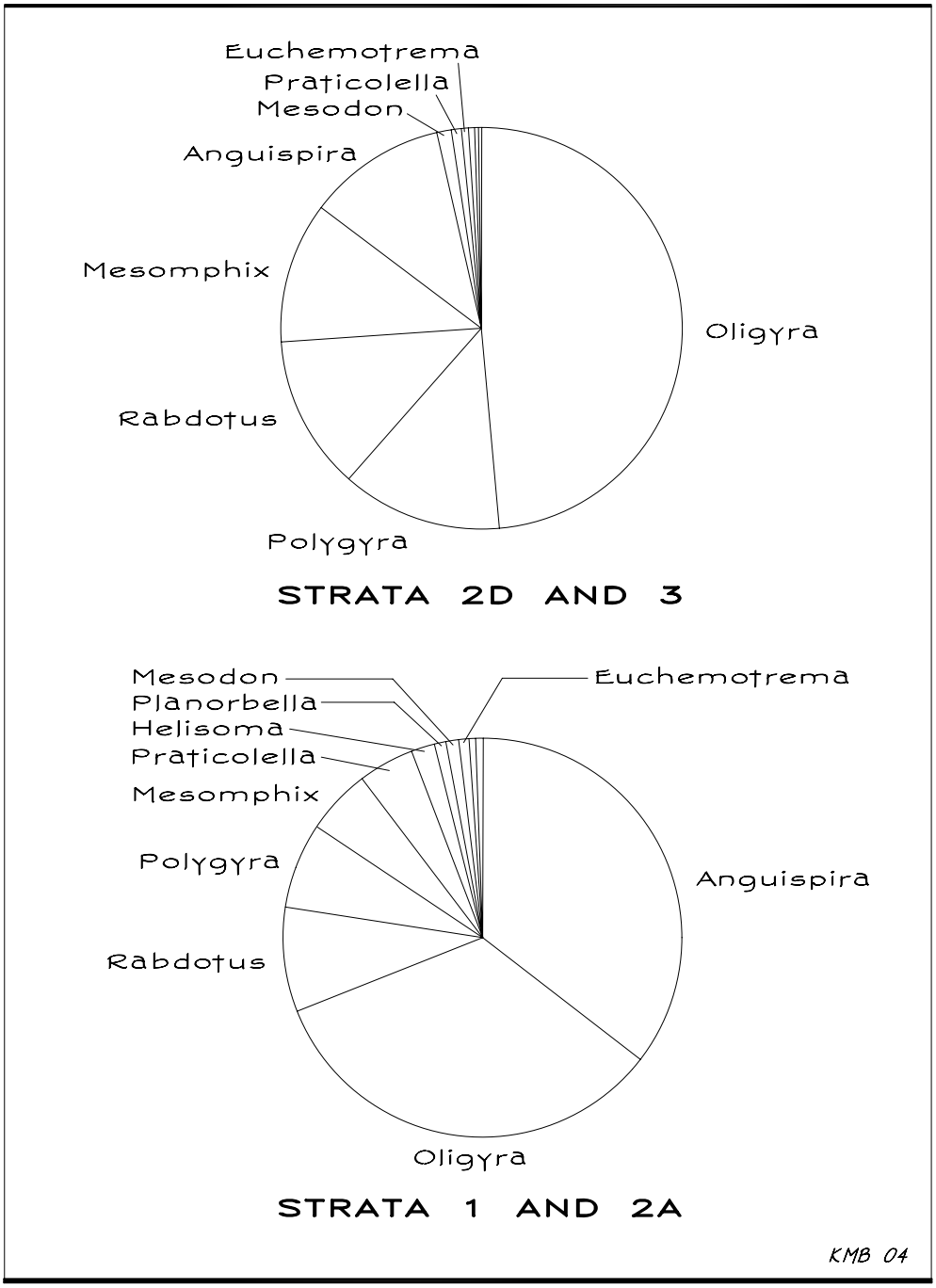


Figure 8.26. Principal Taxa From the Quarter-Inch Screen, Upper and Lower Part of the Bench Deposits. Microsnails and counts from stratum 2B are omitted. The chief difference is the reduction in *Anguispira* in the upper diagram.

Opercula and Snail Eggs

Although shell preservation is poor in the lower part of the bench deposits, it is actually quite good in the upper part, as demonstrated by the recovery of delicate, thin-walled microsnails like *Carychium mexicanum* or *Helicodiscus singleyanus*, and very small, thin-walled, embryonic or juvenile *Rabdotus*, *Anguispira*, *Glyphyalinia*, and other taxa.

Two other kinds of items illustrate the excellent preservation of snail assemblages in the upper part of the bench. Over 600 opercula from *Oligyra orbiculata* were fortuitously recovered while processing snails from the 1/4-inch screen sample (Table 8.10). These small, teardrop-shaped, leaflike bits of shell (Fig. 8.27) can easily fall through 1/4-inch mesh, so thousands of them were probably present in the sediment that was screened, and those recovered are probably a very small fraction of the number that were originally present. they are common inclusions in south Texas archeological sites. There are other operculate species (such as *Pomatiopsis lapidaria* and *Valvata tricarinata*) present, but none of their opercula have been found. As Table 8.10 shows, the distribution of opercula is similar to that of shells – most are confined to stratum 2D and above, except in unit N112 E97, where significant numbers were found in stratum 2C. Only a few specimens were found in stratum 2A, and none from the 1/4-inch screen in stratum 1.

Table 8.10. Stratigraphic Distribution of Opercula from *Oligyra orbiculata*.

N109 E103	Count	Stratum
93.14-92.90	31	2D/3
92.90-92.85	20	2D/3
92.85-92.80	20	2D
92.80-92.75	7	2D
92.75-92.70	4	2D
92.70-92.65	9	2D
92.65-92.60	6	2C/2D
92.60-92.55	6	2C
92.55-92.50		2B/2C
92.50-92.45	1	2B
92.45-92.40	1	2B
92.40-92.35	1	2B
92.35-92.30		2B
92.30-92.25		2B
92.25-92.20	1	2B
92.20-92.15		2A/2B
92.15-92.10	2	2A
92.10-92.05		2A
92.05-92.00		1/2A
92.00-91.95		1
91.95-91.90		1
N110 E102		
93.08-92.90	3	3*
92.90-92.80	7	2D/3
92.80-92.75	13	2D
92.75-92.70	7	2D
92.70-92.65		2C
92.65-92.60	4	2C
92.60-92.55	2	2B/2C
92.55-92.50		2B/2C
92.50-92.45	1	2B
92.45-92.40		2B
92.40-92.35		2B
92.35-92.30		2B
92.30-92.25		2B
92.25-92.20		2A/2B
92.20-92.15	1	2A/2B
92.15-92.10	1	2A
92.10-92.05		2A
92.05-92.00		2A
92.00-91.95		2A/2A calcrete
91.95-91.90		2A calcrete
91.90-91.85		1/2A calcrete
91.85-91.80		1
91.80-91.75		1
91.75-91.70		1
91.70-91.65		1
91.65-91.60		1
91.60-91.55		1
N111 E101		
92.89-92.80	4	2D/3
92.80-92.70	26	2D
92.70-92.65	4	2C/2D
92.65-92.60	14	2C
92.60-92.55	6	2B/2C
92.55-92.50	3	2B
92.50-92.45		2B
92.45-92.40		2B
92.40-92.35		2B
92.35-92.30	1	2B
92.30-92.25	1	2B
92.25-92.20		2A/2B
92.20-92.15		2A
92.15-92.10	1	2A
92.10-92.05		2A
92.05-92.00		2A
92.00-91.95		1/2A
91.95-91.90		1
N112 E99		
92.89-92.60	11	2C/2D
92.60-92.55		2B/2C
92.55-92.50	1	2B
92.50-92.45		2B
92.45-92.40		2B
92.40-92.35		2B
92.35-92.30		2A/2B
92.30-92.25		2A/2B
92.25-92.20		2A
92.20-92.15		2A
92.15-92.10	1	2A
92.10-92.05		1/2A
92.05-92.00		1
92.00-91.95		1
91.95-91.90		1

(continued on next page)

(Table 8.10 continued)

N112 E97	Count	Stratum
93.14-92.75	68	2D/3
92.75-92.70	81	2C/2D
92.70-92.65	10	2C
92.65-92.60	7	2C
92.60-92.55	3	2B/2C
92.55-92.50	2	2B
92.50-92.45		2B
92.45-92.40		2B
92.40-92.35		2B
92.35-92.30		2B
92.30-92.25		2A/2B
92.25-92.20	1	2A
92.20-92.15		2A

N109 E96	Count	Stratum
93.08-93.00	31	2D
93.00-92.95	23	2D
92.95-92.90	30	2D
92.90-92.85	34	2D
92.85-92.80	48	2D
92.80-92.75	24	2D
92.75-92.70	8	2D
92.70-92.65	9	2D
92.65-92.60	7	2D
92.60-92.55	4	2D
92.55-92.50	5	2C/2D
92.50-92.45		2C
92.45-92.40	1	2C
92.40-92.35	1	2B/2C
92.35-92.30	1	2B
92.30-92.25		2B
92.25-92.20		2A
92.20-92.15	1	2A
92.15-92.10		2A
92.10-92.05		2A
92.05-92.00		2A

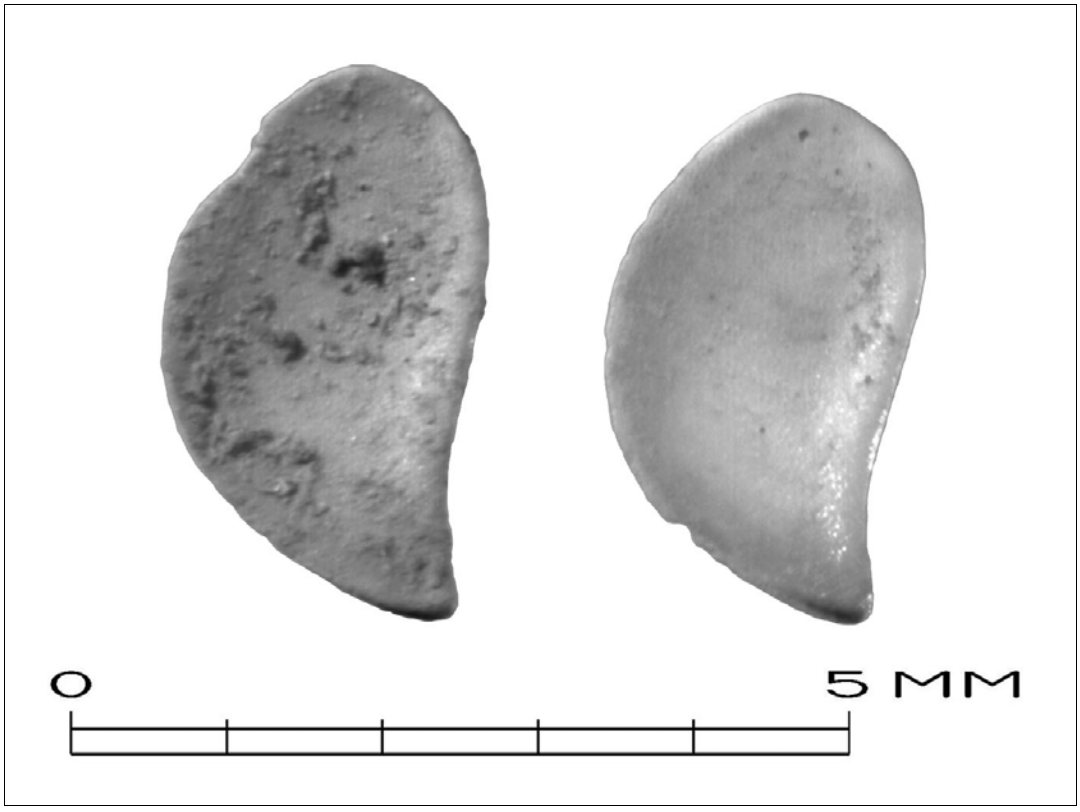


Figure 8.27. Opercula From *Oligyra orbiculata*. Two examples from N109 E96 (92.70-92.65 m), quarter-inch screen sample.

The apertures of the larger shells buried in the bench deposits offer a protected microenvironment, and it is not uncommon to find small bits of charcoal, baked clay, or the shells of juveniles or smaller snail species lodged in sediment filling the aperture. In at least two instances, calcified snail eggs were found lodged in the apertures of adult individuals recovered from the 1/4-inch screen. Besides demonstrating the probably presence of reproducing populations on the site itself, these fragile specimens illustrate the excellent preservation of the snail fauna in stratum 2D and above.

Snail eggs have been previously recovered from Pleistocene and earlier deposits on the Plains and in the Mississippi Valley (Pierce 1993; Tompa 1976, especially Fig. 1). A clutch of calcified eggs was found in the aperture of an adult *Anguispira strongylodes* (16.7 mm in diameter) from N109 E96 (92.85-92.80 m, Lot B-128) recovered from the 1/4-inch screen (Fig. 8.28). There are two complete or nearly complete spherical eggs about 2.0 mm in diameter, plus fragments of another 4-5 (?) eggs, accompanied by the shell of a juvenile *Glyphyalinia umbilicata* (?). These appear slightly smaller than the 2.2-2.4 mm reported by Hubricht (1952:33-34, as *Anguispira alternata crassa*, obsolete taxonomy) as well as those of the related species, *Anguispira alternata*, which has eggs reported to be 2.5 mm in diameter by Gugler (1963:198), or 2.27-2.52 mm by Kingston (1966:531), or 2-3 mm by Elwell and Ulmer (1971:205). *Anguispira alternata* eggs are laid in clutches of 9 to 28 according to Kingston (1966:531) or 2 to 25 according to Elwell and Ulmer (1971:205). These eggs are presumed to be from a gravid individual that died in the spring or early summer before ovipositing, although it should be noted that another *Anguispira* shell from the same lot contained two very small juvenile *Anguispira* that had already hatched, and were presumably fortuitously lodged in the shell aperture.

In another example, remains of two spherical calcified eggs (Fig. 8.29) were found in the aperture of an adult *Mesomphix friabilis* shell from the 1/4-inch screen sample in N109 E96 (92.70-92.65 m, Lot B-131). These are essentially identical in size (both 2.1 mm diameter) and appearance to the *Anguispira* eggs, and the possibility exists that they represent an instance of an *Anguispira* individual using an empty *Mesomphix* shell for oviposition.

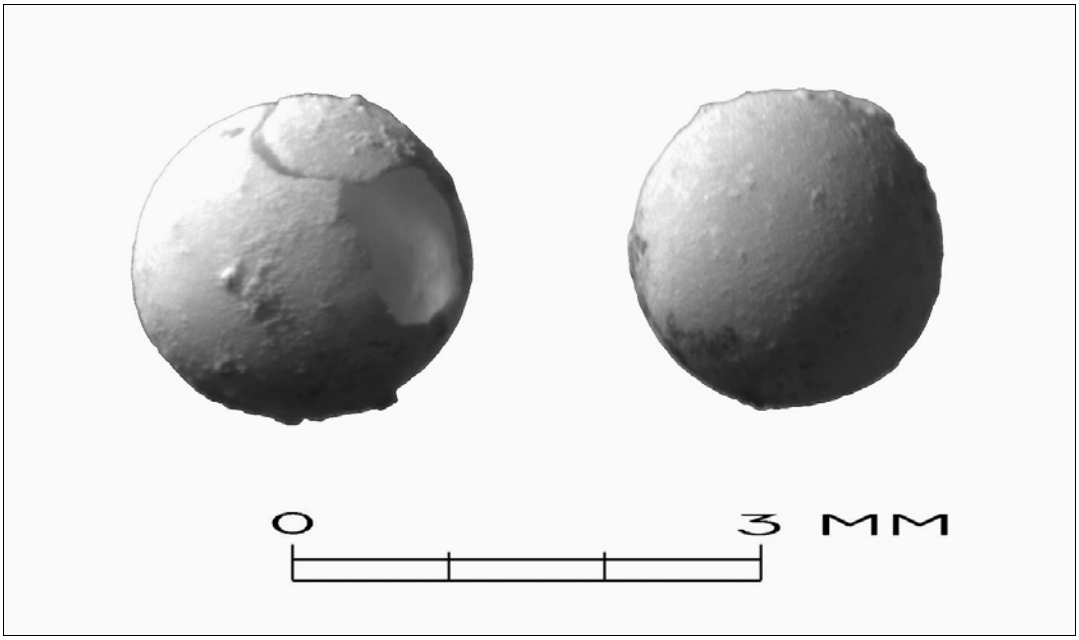


Figure 8.28. Calcified Eggshells From *Anguispira strongylodes* Aperture. Presumed to be *Anguispira* eggs, these came from N109 E96 (92.85-92.80 m). These are the two most complete specimens.

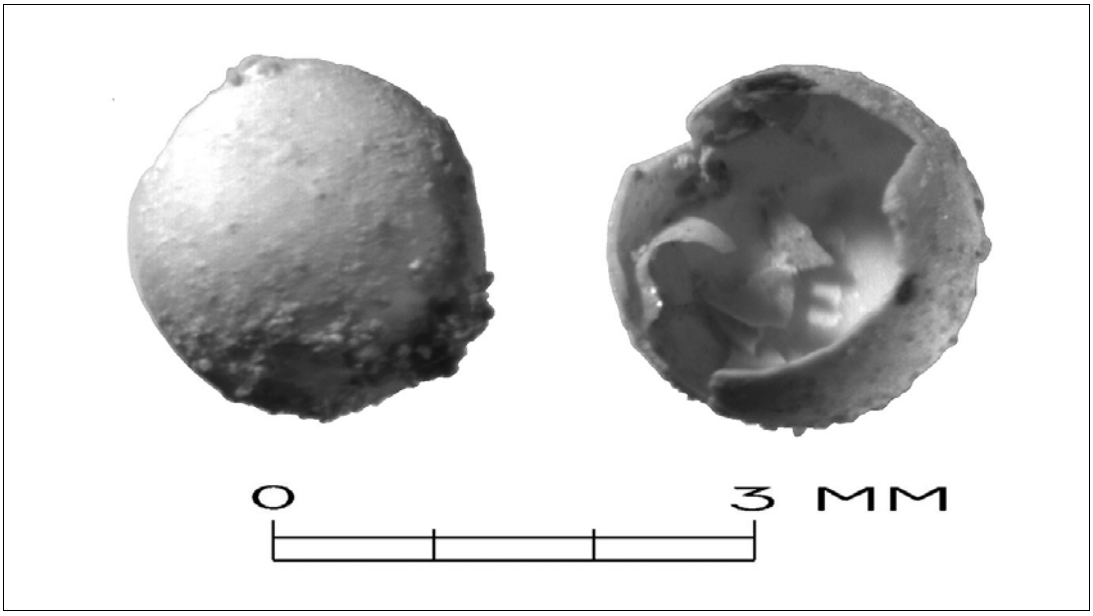


Figure 8.29. Calcified Eggshells From *Mesomphix friabilis* Aperture. Found in N109 E96 (92.70-92.65 m).

All of these eggs are smaller than those reported by Conkin, Conkin and Mason (1962:49, Plate 1, Fig. 14) from Angelita Terrace deposits at the Fordyce Quarry in San Patricio County.

Snail Faunas as Death Assemblages

Except for the live succineids collected on the Preiss Ranch, and some of the faunas collected by Raymond Neck, all of the snail assemblages discussed here, including the Preiss Ranch collections, are death assemblages. Studies of marine mollusks where both live and dead individuals are collected from the same area show that, on average, death assemblages contain about 25% more species than live assemblages, due to the effects of time-averaging. Likewise, there are usually more dead individuals than live, so abundance is time-averaged as well. On the other hand, relative abundance rankings are more robust and are usually more comparable between live and dead assemblages (Kidwell 2002).

It is likely that archeological snail faunas are similarly inflated in species richness and abundance due to time-averaging, and this may be responsible for some of the contrasts between archeological and contemporary faunas seen at various places in Texas. On the other hand, Neck (1987) has presented good evidence for progressive extirpation of species – in other words, some taxa simply drop out of the record during the Holocene, never to reappear, regardless of how well sampled the modern fauna might be. All of these factors (time-averaging, sampling and extraction methods, mesh size, and taphonomic biasing) must be considered when comparing contemporary and archeological faunas.

SPECIES ACCOUNTS

The following long section presents a brief resume of each species found in the bench deposits. While these may be of little interest to the general reader, it is here that specific information on habitat preference or taxonomic ambiguity will be found, and I recommend reading at least the accounts for a few of the key species, like *Carychium mexicanum*, *Gastrocopta contracta*, *G. pellucida*, *Pomatiopsis lapidaria*, *Cincinnatia integra*, and *Valvata tricarinata.* For each, I list the counts from the snail matrix columns and 1/4-inch screen samples. Counts from bulk matrix in N109 E96 are not listed because the inventory is not complete. There are many more snails in those samples, but I have no final count. Each account will list any difficulties in identification or classification, a summary of habitat preferences, and some indication of where the taxon has been found in the archeological or paleontological landscape. Table 8.11 is a comprehensive species list for the bench deposits, with taxon code names for use in tables and diagrams. Table 8.12 is a suggested taxonomy for the land and amphibious species only, based on Burch and Pearce (1990). Note that this is only one of many competing recent taxonomies, and it differs from the older conventional taxonomy. For example, the family Polygyridae in the older taxonomy is here replaced by the family Mesodontidae.

TAXONOMIC REVISIONS SINCE 1982

The first assessment of the snail fauna was a study of two sieved matrix columns done in 1982 by Raymond Neck. This has served as the foundation for all subsequent work, but I have revised some of the taxonomy used then because 1) a few of the species names have changed since then; 2) a few detailed studies of specific taxa by other malacologists (for example, Hubricht 1983 and Pratt 1981) have led to better

understanding of classifications; 3) I have done metric studies on some taxa that have some bearing on classification; and 4) I have found some taxa that I believe were either not present in the matrix columns or might have been overlooked. The taxonomic changes that I have made since Neck's original 1982 study are as follows.

1) Change *Praticolella berlandieriana* to *Praticolella pachyloma*. Based on Hubricht (1983), I believe essentially all the *Praticolella* at Berger Bluff fit the definition of *P. pachyloma* better than *P. berlandieriana*, as used by Neck.

2) Change *Rabdotus mooreanus* and *Rabdotus dealbatus* to *Rabdotus* sp. I suspect that the *Rabdotus* in the bench deposits fit the definition of *R. dealbatus* best, but identification is ambiguous. See discussion in species accounts.

3) Change *Stenotrema leai aliciae* to *Euchemotrema leai*. The genus name has changed, and I believe the subspecies is uncertain.

4) Change *Helicina orbiculata tropica* to *Oligyra orbiculata*. The genus name has changed, and studies have shown the subspecies name has little significance.

5) Add *Mesodon* cf. *M. roemeri*. Neck did not recognize any *Mesodon roemeri* (a central Texas species) in the deposits, but I believe some of the specimens fit the morphology best.

6) Add *Glyphyalinia* cf. *G. roemeri*. Neck classified all *Glyphyalinia* as *G. umbilicata*, but three specimens from the 1/4-inch screen sample seem to fit the description *of G. roemeri*.

7) Change *Polygyra* to *Polygyra texasiana triodontoides*. Most of the *Polygyra* in the bench deposits seem to fit the definition of *P. texasiana triodontoides* best, based on Pratt (1981).

8) Add unidentified slug. Neck found no slug plates in either of the matrix columns, but at least two examples have been found in the N109 E96 bulk matrix samples.

9) Change *Physa virgata* to *Physella virgata*. The genus name has changed.

10) Add Lymnaeidae, cf. *Fossaria* sp. A snail that I believe resembles *Fossaria* has been found since Neck's original work.

11) Change *Helisoma trivolvis* to *Planorbella trivolvis*. The genus name has changed.

Table 8.11. Comprehensive List of Snail Taxa From the Bench Deposits.

Terrestrial species	Taxon code
Anguispira strongylodes	ANGS
Carychium mexicanum	CARM
Euchemotrema leai	EUL
*Gastrocopta armifera**	GARM
Gastrocopta contracta	GCON
Gastrocopta pellucida	GPEL
Gastrocopta pentodon	GPEN
Gastrocopta procera	GPRO
Gastrocopta tappaniana	GTAP
Glyphyalinia umbilicata	GLYU
Glyphyalinia cf. *G. roemeri* (?)	GLYR
Hawaiia minuscula	HAWM
Helicodiscus singleyanus	HELS
Mesodon cf. *M. roemeri* (?)	MROE
Mesodon thyroidus	MTHY
Mesomphix friabilis	MEZF
Oligyra orbiculata	OLIO
Polygyra mooreana	PMOO
Polygyra texasiana triodontoides	PTEX
Praticolella pachyloma (*P. berlandieriana?*)	PRAP
Pupisoma dioscoricola	PUPD
Pupoides albilabris	PALB
Rabdotus dealbatus (*R. mooreanus?, R. alternatus?*)	RAB
Strobilops texasiana	STRO
Zonitoides arboreus	ZONA
Unidentified slug	SLUG
Amphibious species	
Catinella vermeta	CATV
*Pomatiopsis lapidaria***	PLAP
Aquatic species	
Biomphalaria obstructa	BIOO
*Cincinnatia integra****	CINI
Gyraulus parvus	GYRP
Helisoma anceps	HANC
Lymnaeidae, cf. *Fossaria* sp. (?)	LYM
Physella virgata	PHYV
Planorbella trivolvis	PTRI
*Valvata tricarinata***	VALT

* Now only approximately west of Balcones Escarpment; extirpated from Gulf Coastal Plain?

** Extirpated in Texas.

*** Listed by Fullington (1978:20) as “Fossil, potentially recent” but apparently surviving sparsely in Coleto Creek and lower Guadalupe River drainages.

Table 8.12. Taxonomy of Land and Amphibious Snails From the Bench.

Class Gastropoda
- Subclass Prosobranchia
  - Order Archaeogastropoda
    - Suborder Neritopsina
      - Superfamily Neritoidea
        - Family Helicinidae
          - *Oligyra orbiculata*
  - Order Mesogastropoda
    - Superfamily Truncatelloidea
      - Family Pomatiposidae
        - *Pomatiopsis lapidaria* [amphibious]
- Subclass Pulmonata
  - Order Acteophila
    - Superfamily Auriculoidea
      - Family Carychiidae
        - *Carychium mexicanum*
  - Order Geophila
    - Suborder Orthurethra
      - Superfamily Pupilloidea
        - Family Stroblipsidae
          - *Strobilops texasiana*
        - Family Pupillidae
          - Vertigininae
            - *Pupisoma dioscoricola*
          - Pupillinae
            - *Pupoides albilabris*
          - Chondrininae
            - *Gastrocopta armifera*
            - *Gastrocopta contracta*
            - *Gastrocopta pellucida*
            - *Gastropcopta pentodon*
            - *Gastrocopta tappaniana*
    - Suborder Heterurethra
      - Superfamily Succinoidea
        - Family Succineidae
          - *Catinella vermeta (avara)* [amphibious]
    - Suborder Sigmurethra
      - Infraorder Holopodopes
      - Superfamily Orthalicoidea
        - Family Orthalicidae (= Bulimulidae)
          - *Rabdotus dealbatus*

(Table 8.12, continued)

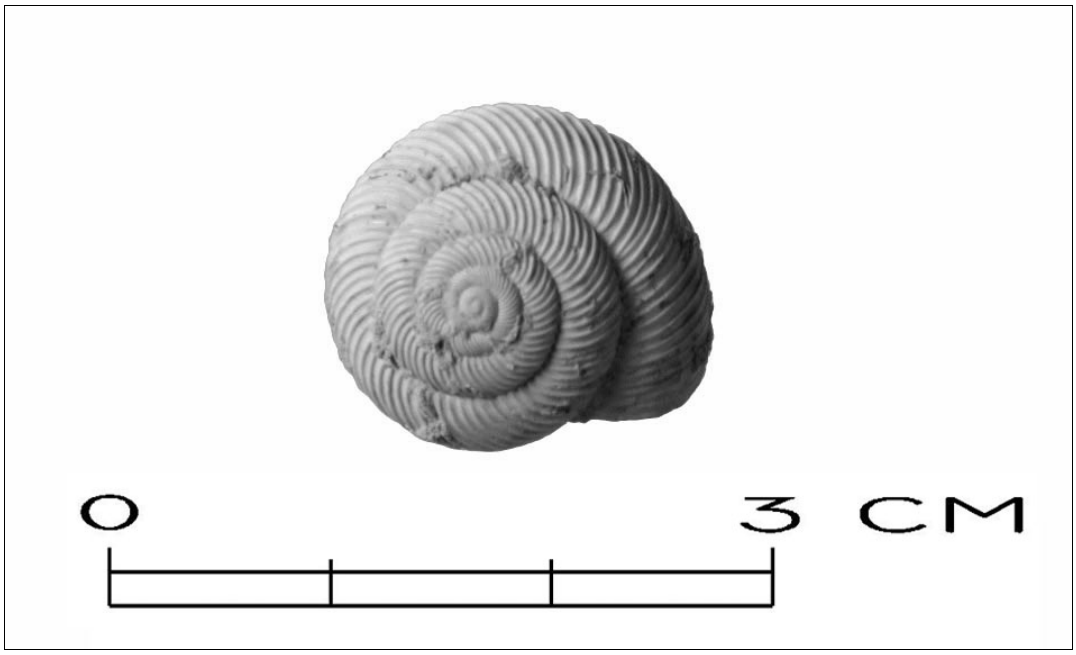
Infraorder Aulacopoda
Superfamily Arionoidea
Family Helicodiscidae
Helicodiscus singleyanus
Family Discidae
Anguispira strongylodes
Superfamily Limacoidea
Family Vitrinidae
Zonitinae
Glyphyalinia umbilicata
Hawaiia minuscula
Mesomphix friabilis
Zonitoides arboreus
Family Limacidae
(*Deroceras laeve*)
Infraorder Holopoda
Superfamily Mesdontoidea
Family Mesodontidae
Mesodontinae
Mesodon cf. *M. roemeri*
Mesodon thyroidus
Polygyra texasiana triodontoides
Praticolella pachyloma
Euchemotrema leai

Adapted from Burch and Pearce (1990:206-210); aquatic snails are not listed.

TERRESTRIAL SNAILS

Anguispira strongylodes (Fig. 8.30), ANGS

Matrix columns: 372 specimens
1/4-inch screen sample: 1225 specimens
Body size: Large bodied, adults from the bench deposits about 13.0-19.7 mm in diameter



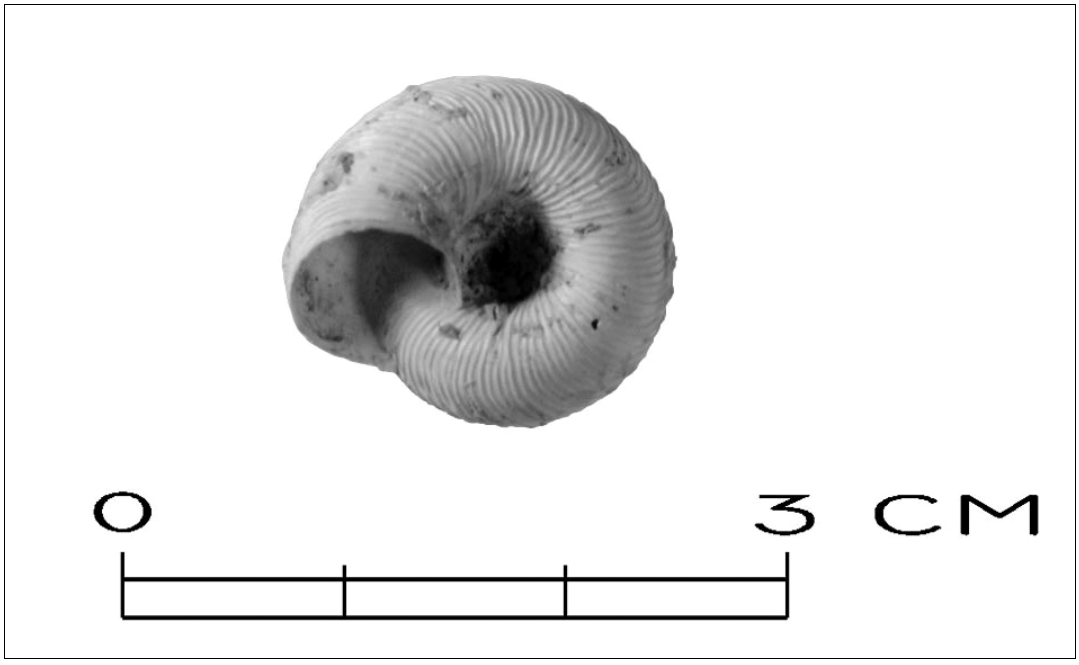


Figure 8.30. *Anguispira strongylodes*. Top, apical view; bottom, umbilical view. N112 E97 (93.14-92.75 m), Lot B-112.

This species was originally classified as a weakly banded subspecies (*Anguispira alternata strongylodes*) of *Anguispira alternata* by Pilsbry (1948:577) and has only recently been elevated to specific status. Consequently, although *A. alternata* is one of the most studied and best described North American snails, almost nothing has been published specifically about *Anguispira strongylodes*. Under current taxonomy, *A. alternata* occupies the northern part of the eastern US (Hubricht 1985:Map 158) *and A. strongylodes* the southern part (Fig. 8.3), including Texas. Previous references *to A. alternata* in Texas can now be linked to *A. strongylodes*. The genus has many variants (see MacMillan 1940). Pilsbry lists the diameter as 18 mm, but the largest adults from the bench deposits average about 17 mm, and the largest specimen is 19.7 mm in diameter. Juveniles of various sizes are common, down to embryos as small as 1.7 mm in diameter. According to Elwell and Ulmer (1971:209), newly hatched *A. alternata* are about 2 mm in diameter, so the smallest shells 1.7-1.8 mm in diameter represent "stillborn" hatchlings. Juveniles from the bench deposits may equal or outnumber adults, and indicate the presence of a breeding population on or near the site. According to Elwell and Ulmer (1971:204), ovipositing *A. alternata* are 13 mm in diameter or larger, so adult *A. strongylodes* are presumed to be at least 13 mm in size (shells 8 mm in diameter are about 14.5 weeks old). The shell is prominently ribbed and fairly thick-walled and sturdy, and consequently may be slightly overrepresented in the deposits compared to less robust species. Even small fragments can easily be identified by the ribbing. Sometimes known by the common name "Southeastern Tigersnail," *A. strongylodes* is characterized by weak orange banding on the shell exterior. Banding is best developed on juveniles rather than embryos or adults, and is strongest in the upper part of the bench, in stratum 2B or above, but occasional banded individuals were found as deep as stratum 2B. This is the only pigmented species found in the bench deposits.

Anguispira strongylodes is chiefly a woodland snail (Hubricht 1985:18) reaching its southwestern limit in the counties of De Witt, Victoria, and San Patricio (McGee 1965:90). Hubricht (1964:32, as *A. alternata crassa*) found it under logs in pine-hardwood forest in the Sulphur River bottom, Cass County. In Tennessee, it was found to prefer limestone substrates, moist soils, and steep forested slopes (Coney *et al*. 1982:83, 93). Habitat preferences of the closely related species *Anguispira alternata* are fairly well documented. The species is colonial (Leonard 1959:130) and occurs in wooded floodplains and moist upland wooded areas (Amaral and Witter 1973:421; Baker 1935:261-262; Douglas 1963:186; Branson and Batch 1970:344; Metcalf 1962:285; Nekola and Smith 1999). According to LaRocque (1970:671-672, extensive discussion) it is a hardy snail favoring deciduous woodland (often in dead leaves, humus, or under logs or rocks) but able to live in drier, more open areas (see also Leonard 1959:130). In Iowa, Elwell and Ulmer (1971:204) report

> *Anguispira alternata* was found predominantly in well-established deciduous forests with mesic soil conditions and generally low light intensities during the summer. They were most numerous on north-facing slopes where there were downed trees in various stages of decomposition and abundant leaf litter in fall, winter and spring… Best collecting sites in fall and early spring were leaf-clogged spillways, perhaps because of greater water retention. In at least one collecting area there was a conspicuous size differential between snails found on and in the soil and those found under bark on decaying trees. Larger snails (8-19 mm) were found on the soil surface or at depths of approximately 2-3 cm; smaller ones (3-7 mm) were found under bark on decaying trees.

In the bench deposits, the large component of *Anguispira strongylodes* is regarded as an indicator of well-developed deciduous woodland (both on the floodplain and valley slopes) and abundant decaying wood (a signal of mature forest) in the Younger Dryas and early Holocene. The strong presence of juveniles in the deposits probably indicates heavy deciduous canopy and downed wood on or very near the site. The related species

Anguispira alternata is occasionally found as a minor taxon in grasslands, provided cover in the form of logs or rocks is available (see Theler 1997:Table 4), but the genus is a typical eastern woodland snail and rarely extends very far onto the Plains. Daily minimum distances traveled by these snails average only about 41 cm, but may be as much as 3.25 m (Karson 1999:Fig. 12).

The stratigraphic distribution of *A. strongylodes* in the bench deposits is variable. It occurs throughout the section, but in nearly all the 1/4-inch screen samples, it is much more abundant at the top of the section (above 92.50 m), generally declining in abundance toward the base. However, this may be chiefly a result of shell breakage during screening, because the frequency curves for *Anguispira* in the two fine-sieved matrix columns (N109 E103 and N110 E102) look very different. In the N110 E102 column, the frequency actually peaks at 92.25-92.20 m, near the base of stratum 2B. In the N109 E103 column, the peak in frequency is at the top of the section, but there are significant numbers of specimens throughout the section.

According to Elwell and Ulmer (1971:206), *Anguispira alternata* forms an epiphragm to seal the aperture and is resistant to desiccation; adults can estivate for several months. They burrow shallowly into the soil in clusters to estivate in the winter months (Douglas 1963:192; MacMillan 1940:380); whether the southern form, *Anguispira strongylodes* also does this is unreported. The snails will climb to avoid immersion in water.

Anguispira strongylodes has been recovered archeologically in east and southeast Texas and in the eastern part of central Texas (Amaral and Witter 1973; Brown and

Hughes 2003:126; Bond 1978:Table 4; Fullington 1995:Table H-1; Gardner 2000:221-222; Shaw *et al*. 1998; Kirby and Reeder 1980; Moore *et al*. 1996), where it is listed as *A. alternata* in the older literature. According to Simmons (1956), it is found in Central Texas burned rock middens, although it is rarely mentioned in any of the recent literature on such sites. Curiously, only a single specimen was found at the Guadalupe Bay site (Fullington 2002a:Table 13-1), and none were found at the Smith Creek Bridge site (Brown 2002). None were found in surveys of the modern and recent fauna on the Preiss Ranch, and none were seen anywhere in my diatom sampling throughout the Berger Bluff catchment, although several *Mesodon* specimens (a taxon often associated with *Anguispira*) were found. Raymond Neck also reported it from Victoria and from Goliad State Park (Table 8.5). It is reported from 41 GD 21 (Fox 1979:Table 8).

The species is reported from Pleistocene terrace deposits on Clear Creek, Denton County, near the Aubrey site (Cheatum and Allen 1963:175) but not from the Aubrey site (Neck 2001). It is reported from the Lewisville site (Crook and Harris 1957:57). Conkin, Conkin and Mason (1962:38) reported it from Pleistocene terrace deposits on the Nueces River (Fordyce Quarry, San Patricio County). These specimens (reported as *Anguispira alternata*) ranged in diameter from 16.2 to 18.0 mm. The location is well to the south of its present southern limit in Goliad County. Three specimens were also found at the Pavo Real site (Brown 2003:270). here again, the species is to the south of its present limit in Comal County.

Carychium mexicanum (Fig. 8.31), CARM

Matrix columns: 336 specimens
1/4-inch screen sample: 4 fortuitously recovered specimens
Body size: Microsnail, maximum height 1.7-2.0 mm (Fullington and Pratt 1974:10)

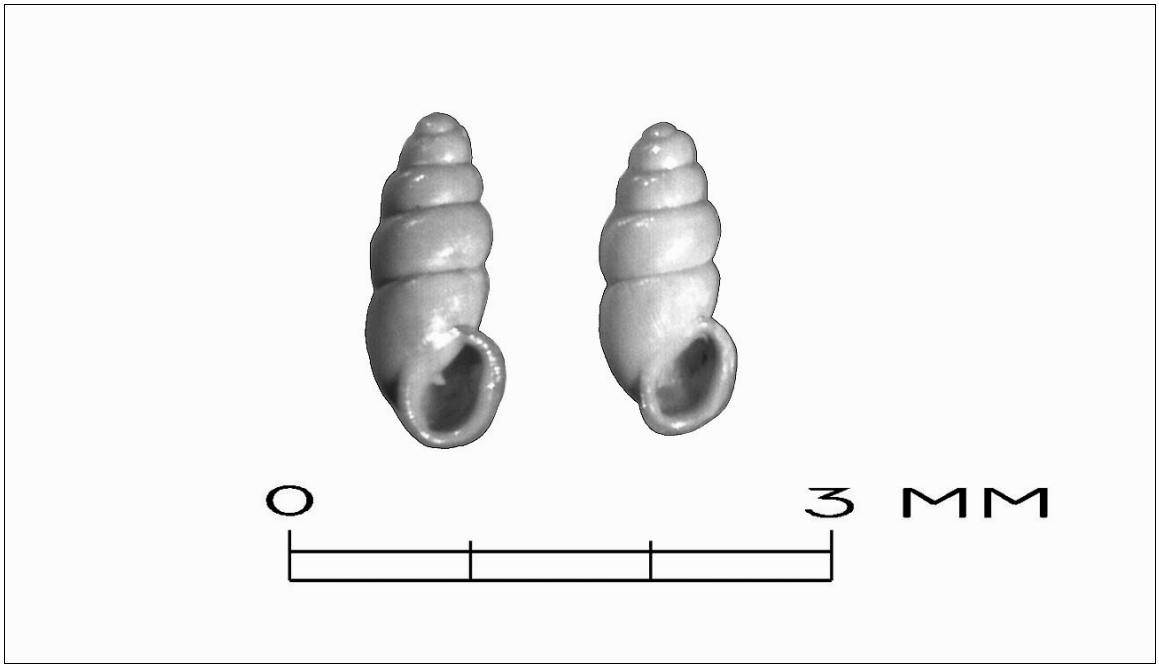


Figure 8.31. *Carychium mexicanum*. Two specimens from N109 E96 (92.85-92.80 m), Lot B-128.

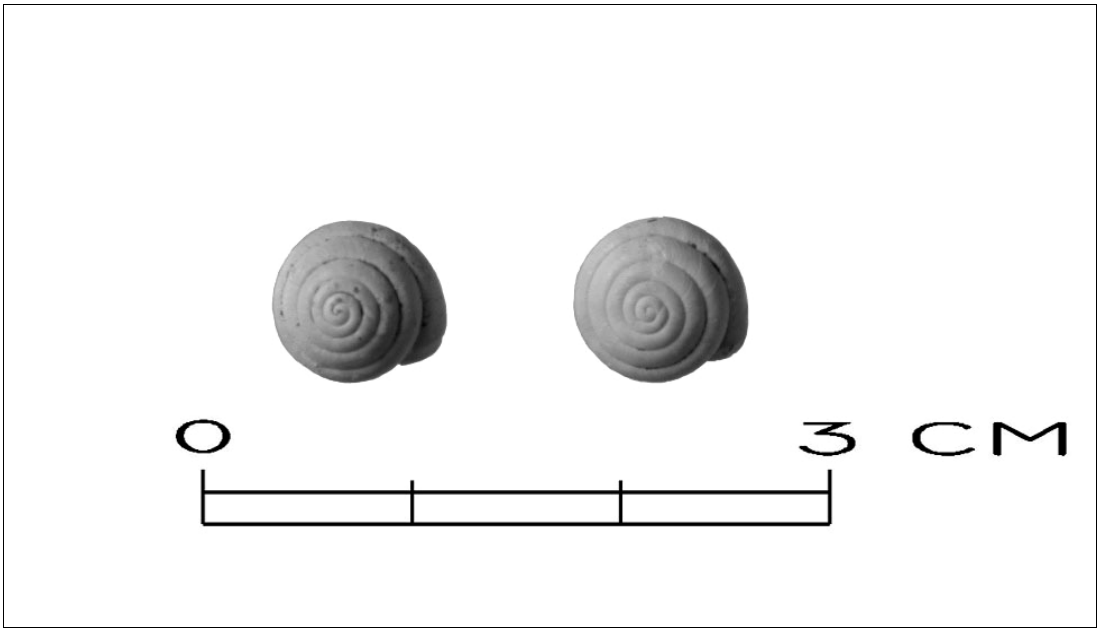
This is the smallest snail found in the bench deposits. High quality SEM photos, including detail of the surface texture, have been published by Burch and Van Devender (1980:Figs. 63-65, 67-68). A surprising number were recovered by fine mesh sieving of the matrix columns, and the near absence of the species from the 1/4-inch screen sample is due to its small size. The species is stratigraphically concentrated, mostly in the upper part of stratum 2B, with a secondary concentration in stratum 2A or 1. This is a coastal plain species (Fig. 8.4; Hubricht 1985:Map 14; Burch and Van Devender 1980:Fig 73), perhaps temperature-limited at the northern edge of its range, but in Texas, it occupies most of the eastern half of the state (Fig. 8.8). Correa Sandoval (2003) reports it from Nuevo León, Tamaulipas, and San Luis Potosí, and it apparently extends as far south as Guatemala (Pilsbry 1948:1060). Fullington and Pratt (1974:9, 10) observe that

"generally, the carychiids are found only in moist or wet places in old logs or under masses of decaying, wet leaves…. *Carychium mexic*anum in Texas is found in leaf litter, usually on a floodplain. it is often common where it occurs, but is sporadic in its distribution." Hubricht notes "Found in wetter habitats than *C. exile*, although they are sometimes found together. In Florida it is usually found in swamps. Common in eastern Mexico" (Hubricht 1985:6). Fullington (1978a:113) also notes that "it is generally in close association with water and has been collected crawling in submerged moss." A related species, *C. exile*, is sometimes found as a marsh snail, and another related species, *C. exiguum*, is frequently found as a Pleistocene fossil in Southern Plains sites.

Because *Carychium mexicanum* is so small, it is often overlooked both in contemporary surveys and in archeological recovery. Although practically *Carychium* on the high Plains are *C. exiguum*, Fullington (1978a:113) nevertheless reports *C. mexicanum* as present at the Rex Rodgers site, far to the northwest of its present distribution. It has also been found at 41 MM 340 and 341 (Fullington 2001), Denton Creek (Neck 1994a:Table 17), Wilson-Leonard (Shaw *et a*l. 1998:Table 37-3) and the Perry site in Freestone County (Fullington 1987), and Raymond Neck (1986a) recovered contemporary specimens from screened leaf litter at Kenyon Rockshelter, but did not find any in the archeological deposits. It can be regarded as a good mesic floodplain indicator in the bench deposits. I list it here as terrestrial rather than amphibious. The drift sample from the Preiss Ranch contained 59 specimens (Table 8.9).

Euchemotrema leai (Fig. 8.32), EUL

Matrix columns: 13 specimens
1/4-inch screen sample: 54 specimens
Body size: Medium-bodied, diameter 7.0-9.3 mm (Cheatum and Fullington 1971:41-42), 8.5-9.2 mm (Logsdon 1967:77-78), 6.5-8.5 mm, height 3.5-5.6 mm (Branson 1969:389)



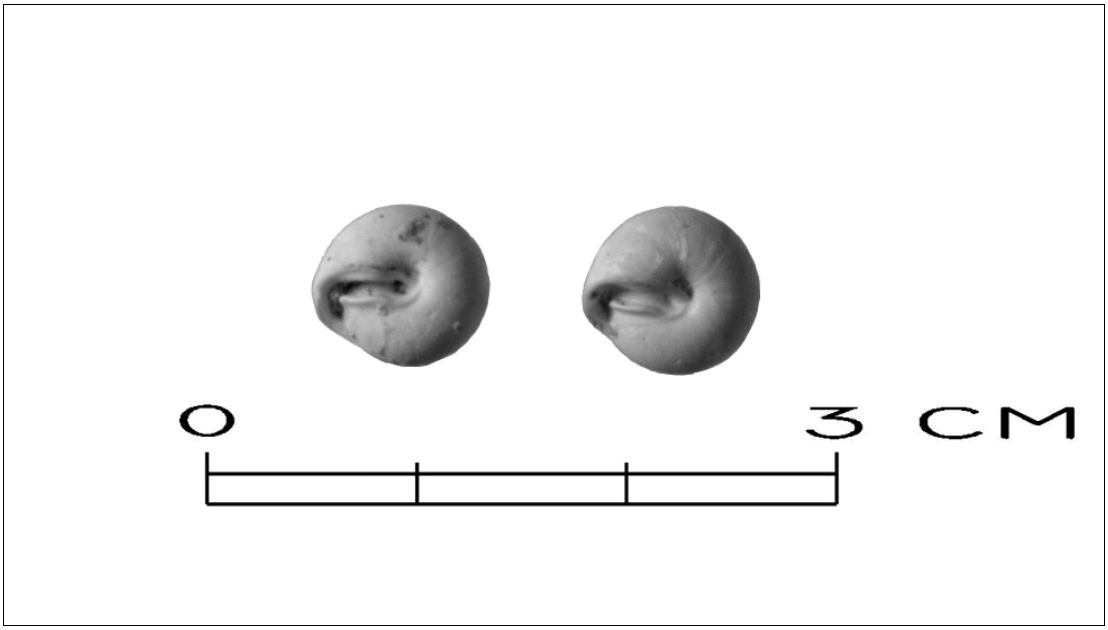


Figure 8.32. *Euchemotrema leai*. *Top*, apical view; *bottom*, umbilical view. Both specimens from N109 E103 (92.70-92.65 m), lot B-10.

These distinctive medium-bodied polygyrids were formerly termed *Stenotrema leai aliciae*, and appear as such in most of the published literature. A related subspecies, *Euchemotrema leai cheatumi*, is reported from Palmetto State Park, near Ottine in Gonzales County (note that some of the measured specimens reported by Cheatum and Fullington also come from here), but does not seem to be present at Berger Bluff. The latter is smaller and shallower in profile (Fullington 1974). Specimens from the bench deposits are apparently all examples of the *aliciae* subspecies. For specimens from the 1/4-inch screen, the mean diameter is 8.54 ± 0.33 mm (range, 7.8-9.2 mm, N = 40). The mean shell height is 5.57 ± 0.29 mm (range, 5.0-6.2 mm, N = 28). Shells are reasonably durable, although prone to collapsed spires. The parietal teeth are poorly attached and are often missing from the bench specimens.

Regarding habitat preference, Hubricht (1985:41) says "usually found in meadows, along roadsides, and near springs, but also found in floodplain woods." Logsdon (1967:77) reports "found in damp places under logs, bark or leaves; near water." Metcalf (1962:282-283) reports the species "was most abundant along the wooded floodplain of the Arkansas River under leaf litter and decaying logs and branches." Leonard (1959:87) says "The typical subspecies inhabits very humid areas… found in Kansas both in the moist wooded areas of the eastern part of the State and in the more open situations of the central third, while occasional local populations are known in wooded areas associated with streams in the western third." Basch, Bainer and Wilhm (1970:568): "In all cases, this species was collected on the reservation in wooded or shaded areas having a fair amount of moisture. It was most common around the limestone ledge in C33, but was not abundant anywhere. At the five stations where this species was collected, shells were found under decaying logs, in leaf mold and in other decaying plant

parts." LaRocque (1970:568) says "damp places near water" and gives a detailed synopsis. Further habitat descriptions can be found in Goodrich and van der Schalie (1944:266, as *S. monodon*), Leonard and Goble (1952:1040), and Branson and Batch (1970:339). it is absent from the Southern Plains Gastropod Survey.

This species occurs throughout the lower Mississippi River Valley, north to Kansas and Iowa, east into Georgia and Kentucky (Hubricht 1985:Map 427). In Texas, it occupies the eastern half of the state, except in south Texas where it is largely confined to the coast (Fig. 8.11). Archeological examples have been recovered from the Domebo site (Cheatum and Allen 1966:38-39), the Lewisville site (Crook and Harris 1957:57), the Aubrey site, Lake Theo, the Smith Creek Bridge site, the Guadalupe Bay site, the Gaulding site, 41 FB 34 (Neck 1986b), FB 199, FB 200, the Berclair Terrace (Conkin and Conkin 1962:Fig. 5, 6, as *Stenotrema monodon aliciae*) and the Pavo Real site. Paleontological localities include the Stillhouse Hollow site (Cheatum and Slaughter 1966:53), Wood Pit Pond (Slaughter et al. 1962:48), Fordyce Quarry (Conkin, Conkin and Mason 1962:29) and various undated Central and South Texas exposures reported by Hubricht (1962).

In the bench deposits, this species is interpreted as an indicator of mesic riparian woodland with abundant leaf litter and rotting wood.

Gastrocopta armifera, GARM

Matrix columns: 1 specimen
1/4-inch screen sample: none
Body size: Microsnail, maximum height 3.7-5.0 mm (Cheatum and Fullington 1973:11)

This is the largest species of *Gastrocopta* in Texas, and although it occurs at many archeological and paleontological sites scattered throughout the Plains, only a single example was found in the bench deposits (N109 E103, 92.40-92.35 m). In Texas, this calciphile species is reported only west of the Balcones Escarpment, except for instances in the far northeast corner of the state (Red River and Bowie County; Cheatum and Fullington 1973:Fig. 2) and seems to be absent from the Gulf Coastal Plain. No specimens were found on the Preiss Ranch, at Victoria or Goliad State Park (Table 8.5), or in Branson's inventory of Colorado and Guadalupe River drift (Table 8.3). From a continental perspective, it has a widespread but spotty distribution, occurring in Appalachia into New England and Ontario (Oughton 1948:50), the central Mississippi River Valley, and throughout the Plains (Hubricht 1985:Map 44), westward into New Mexico, Colorado, Manitoba, Alberta (Metcalf and Smartt 1997:28), and even Alaska (LaRocque 1970:Fig. 574). The shell is comparatively large and barrel-shaped. A series from Comal County recorded by Hubricht (1972:Fig. 4) measures about 4.3-5.0 mm in height and 2.3-2.7 mm in width.

According to Cheatum and Fullington (1973:11), *G. armifera* "usually occurs in calcareous areas under limestone rocks, leaf litter or rotting logs. It may be found in moist situations or on dry sparsely-wooded hillsides." In Kaufman County, Logsdon (1967:49) found it at three sites. It was common in decaying logs at one site, and was also found under leaves and other forest debris (see also Cheatum and Burt 1931:336). In New Mexico, it occurs in brushy areas on hillsides, scarps and along streams (Metcalf and Smartt 1997:28). In Kansas, it is "a gregarious species occurring commonly on wooded slopes, near or removed from a stream. It is to be found under dead wood, limestone rocks, or light cover of leaf mold or other debris" (Franzen and Leonard 1947:329). In the

Southern Plains Gastropod Survey, this species was moderately abundant, but was almost entirely restricted to rock ledges at the east end of the transect, where it occurred with a density of 127 individuals per square meter (Wyckoff, Theler and Carter 1997:37). Another survey in Oklahoma confirms that the species is spotty in distribution, but may occur in fairly high numbers in the few places where it does occur (Metcalf 1984:Table 1), mostly in riparian woodland. In the Texas Panhandle Neck (1990:13) found it in a xeric site with no leaf litter, only downed wood and flood debris as cover. This was the most common species in Theler's (1997:Table 4) inventory of xeric hill prairies in Wisconsin.

This species has been recovered at the Aubrey site (Neck 2001:Table 7.2, 7.3), Lubbock Lake (Pierce 1987:Table 6.1), Lake Theo (Neck 1978: 94, Neck 1987a:316), Wilson-Leonard (Shaw *et al*. 1998), the Hog Creek project (Kirby and Reeder 1980:Table 15.1), the Burnham site (Theler 2003a, 2003b), and many other localities throughout the Plains. The single specimen from the bench deposits may be tentatively regarded as a riparian woodland indicator, but a calciphile species that can tolerate dry and well-drained conditions. Franzen and Leonard (1947:330) have characterized as a eurytopic species, able to estivate in drought conditions.

Gastrocopta contracta (Fig. 8.33), GCON

Matrix columns: 347 specimens
1/4-inch screen sample: 90 fortuitously recovered specimens
Body size: Microsnail, average height 2.2-2.5 mm (Cheatum and Fullington 1973:13); 2.3-2.8 mm (Logsdon 1967:47)

Gastrocopta contracta is one of the most important and informative species in the bench deposits. It is a ubiquitous and rather abundant mesic-adapted species that is

largely replaced in the modern fauna by the more arid-adapted *Gastrocopta pellucida*. It is an eastern US species (Fig. 8.6) extending northward into Ontario (Oughton 1948:50), with a somewhat irregular distribution in Texas (Fig. 8.9) that covers the eastern part of the state with gaps in southeastern and deep eastern Texas. LaRocque (1970:Fig. 676) show one occurrence in Alaska. Populations in the Big Bend and New Mexico are confined to mountainous areas (Metcalf and Smartt 1997:28).

Cheatum and Fullington (1973:13) list habitat preference as "quite similar to *G. armifera*, but seems to prefer areas with greater moisture than is true of *armifera*." According to Neck (1981c:123), "this species usually occurs in riparian woodlands. Although it is usually found in association with [*Pupoides albilabris* and *Gastrocopta pellucida*], it generally requires a more mesic microhabitat." In Kaufman County, Logsdon (1967:46-47) notes it "was abundant in the wooded floodplains of Forney, the wooded sandy loam at Elmo, and the grassy woodlands of the Reese Farm. It was scarce on the plains of the Linehan Farm and the woods which are subject to inundation along Kings Creek…. Specimens were taken from rotten logs, stream debris, under leaves, decaying grass debris, and the rich humus of the Terrell homestead." Branson (1961a:55) says it "is found on moist shaded areas which are abundantly supplied with limestone and rich decaying organic matter; mycophagous." In Tennessee, it "had an affinity for neutral soils of medium moisture content, late stages of forest succession and leaf litter microhabitat." In Kansas, "most of the shells occurred under rocks in fairly moist conditions or under leaf mold in shaded areas" (Basch, Bainer and Wilhm 1961:192) and "collections made in 1961, a year of above normal rainfall, revealed *G. contracta* to be far more abundant than *G. armifera* in habitats where soil was moist due to seepage. At Station W18 hundreds of specimens of this species were found under small logs,

branches and stones in a sparsely wooded area of upland sloughs….” (Metcalf 1962:287). In the Southern Plains Gastropod Survey, this species was moderately abundant but occurred only at the eastern end of the transect, with a density of 505 individuals per square meter in rock ledges, 68 in riparian woodlands, and 52 on toeslopes. It reaches its eastern range limit near the 32-35-inch annual rainfall isohyets (Wyckoff, Theler and Carter 1997:37).

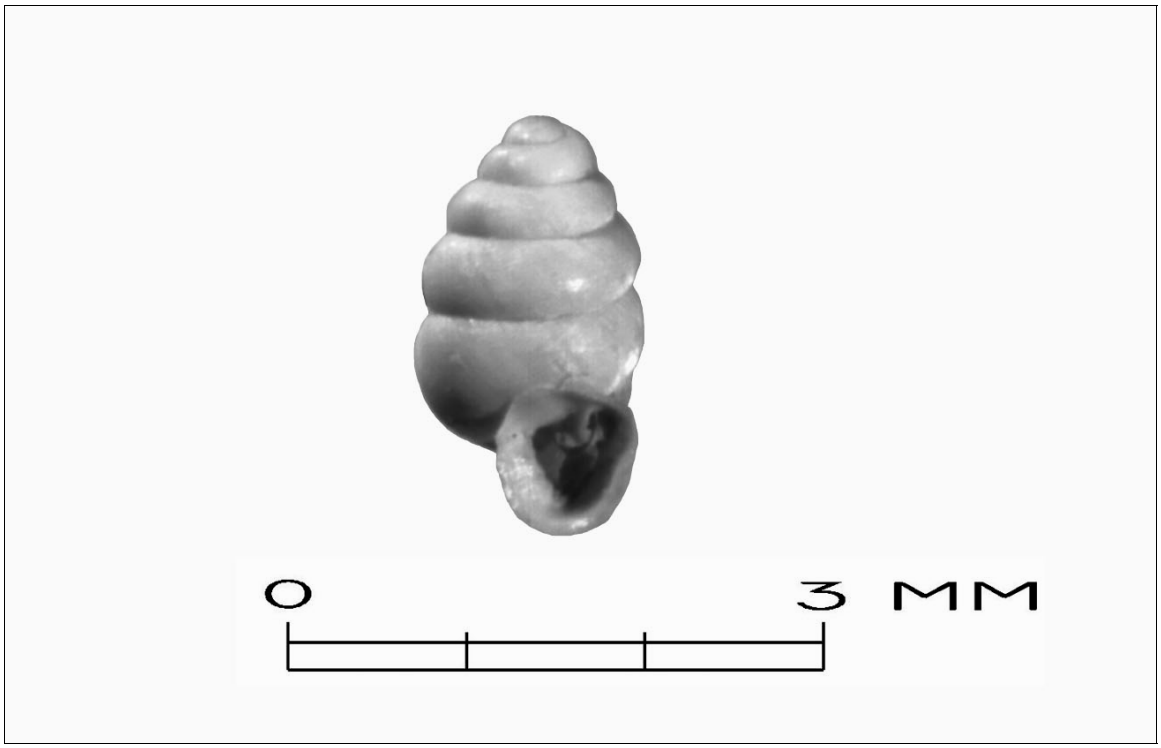


Figure 8.33. *Gastrocopta contracta*. N109 E96 (92.70-92.65 m), Lot B-131.

In the bench deposits, this species is somewhat concentrated in the middle part of the stratigraphic section, mostly in strata 2A, 2B, and 2C. In the two matrix columns, there are 347 *Gastrocopta contracta* compared to only 12 *Gastrocopta pellucida.* In the bulk matrix sample from N109 E96 (92.35-92.30 m) there are 153 *G. contracta* and only

six *G. pellucida*; in the 92.05-92.00 m level, there are 10 *G. contracta* and only one *G. pellucida*. In the local modern fauna, the proportions appear to be reversed. In all the combined Preiss Ranch samples, there are 105 *Gastrocopta contracta* and 335 *Gastrocopta pellucida* (Table 8.13). This reversal is believed to be the result of a contemporary climate that is much more arid than that in the Younger Dryas and early Holocene. Some of this may be due to a taphonomic effect, since the more slender and thin walled *G. pellucida* are more subject to breakage than the robust *G. contracta*. It should also be noted that in the drift samples reported by Branson (1967), the relative proportions are similar to those in the matrix columns – there are about ten times as many *G. contracta* as *G. pellucida* (Table 8.13). In collections at Welder Refuge in San Patricio County, Branson (1960) found about 500 *G. pellucida* compared to 42 *G. contracta*. In the Berger Bluff matrix columns, about 61% of the specimens floated to the surface when the samples were processed.

The species has been recovered at a number of archeological sites, mostly in the eastern part of the state, such as the Aubrey site, Wilson-Leonard, the Mustang Branch site (Neck 1994b:Table 111), Kenyon Rockshelter (Neck 1986a), 41 WM 118 (Amaral and Witter 1973), the Anthon site (Neck 2002:260), the Buckhollow site (Neck 1994c), various sites at Palmetto Bend Reservoir (Neck 1981c), 41 MM 340 and 341 in Milam County (Fullington 2001), the Gaulding site (Fullington 2002b), the Denton Creek site (Neck 1994a:Table 17), 41 FT 193 in Freestone County (Fullington 1987), and 41 DT 59 at Cooper Lake (Fullington 1995), 41 CC 112 in Concho County (Treece 1992:Table 15), as well as the Domebo site (Cheatum and Allen 1966:39) and 34 CD 257 (Fullington and Fullington 1982a) in Oklahoma.

Table 8.13. *Gastrocopta contracta* and *Gastrocopta pellucida* Frequencies.

Brazos and Colorado drift samples (Branson 1967)

	G. contracta	*G. pellucida*
Combined	2477	242

Preiss Ranch samples

	G. contracta	*G. pellucida*
Drift	96	201
D-20	9	129
D-21		4
Wood		1

N109 E103 matrix column

	G. contracta	*G. pellucida*		*G. contracta*	*G. pellucida*
93.14-92.90	26	5	92.40-92.35	8	
92.90-92.85	14	1	92.35-92.30	17	
92.85-92.80	4		92.30-92.25	6	
92.80-92.75	8	2	92.25-92.20	11	
92.75-92.70			92.20-92.15		
92.70-92.65	2		92.15-92.10	6	
92.65-92.60	3		92.10-92.05	9	
92.60-92.55	10	1	92.05-92.00	6	1
92.55-92.50	7		92.00-91.95	2	
92.50-92.45	12		91.95-91.90	2	
92.45-92.40	16				

N110 E102 matrix column

	G. contracta	*G. pellucida*		*G. contracta*	*G. pellucida*
92.90-92.80	7	1	92.20-92.15	18	
92.80-92.75	2		92.15-92.10	11	
92.75-92.70	1		92.10-92.05	3	
92.70-92.65	1		92.05-92.00	12	
92.65-92.60	5	1	92.00-91.95	5	
92.60-92.55	8		91.95-91.90		
92.55-92.50	30		91.90-91.85	1	
92.50-92.45	14		91.85-91.80	1	
92.45-92.40	24		91.80-91.75	1	
92.40-92.35	10		91.75-91.70	1	
92.35-92.30	7		91.70-91.65	1	
92.30-92.25	9		91.65-91.60		
92.25-92.20	5		91.60-91.55	1	

Gastrocopta pellucida (Fig. 8.34), GPEL

Matrix columns: 12 specimens
1/4-inch screen sample: 5 fortuitously recovered specimens
Body size: Microsnail, maximum height 1.9-2.6 mm (Cheatum and Fullington 1973:17); 1.8-2.3 mm (Logsdon 1967:51-52); 1.6-2.6 mm (Branson 1961a:59)

This rather arid-adapted species is the smallest *Gastrocopta*, with a slender, somewhat fragile shell. There are few specimens, and most of them are in the upper part of the section. This may indicate some loss of shells due to fragility, but I doubt it accounts entirely for the scarcity of this species in comparison to *Gastrocopta contracta*. It is much more common in the Preiss Ranch samples, both in the drift sample and the two excavated quadrats (Table 8.13). This species occurs eastward to New Jersey, Florida (Fig. 8.2) and the West Indies and westward into southeastern Colorado, New Mexico, South Dakota, the Chihuahuan Desert (Metcalf and Smartt 1997), Arizona (Bequaert and Miller 1973:80, 171), eastern Utah (Oliver and Bosworth 1999:Fig. 50), Mexico, and Guatemala. In Texas, it is widespread throughout much of the state (Fig. 8.10).

Gastrocopta pellucida "occurs more abundantly in open areas with scattered trees and shrubs. In the Dallas area it has been found associated with grass roots" (Cheatum and Fullington 1973:17). In Kaufman County, Logsdon (1967:52) found it in wooded areas around shrubs and trees, in grass and leaves. Hubricht says "usually found in open, grassy places or in open woods; often in dry, sandy places. In Florida it is sometimes found on the undersides of palmetto leaves" (Hubricht 1985:10). It was the most abundant species in the Southern Plains Gastropod Survey, where almost 6000 specimens were collected, and was especially common in rock ledge microhabitats (with a density of 1142 per square meter). It also occurred in riparian woodland and wooded dunes (Wyckoff, Theler and Carter 1997:35). Elsewhere in Oklahoma, "under rocks and piles of

Bermuda grass" (Branson 1961a:59). In the Texas Panhandle, "this small species is often associated with *G. procera* but is more drought tolerant and is often associated with grass roots" (Neck 1984:71). In Nuevo León, it occurs in open areas with scattered trees and low shrubs and oak-pine-fir (Correa Sandoval 1997:138)

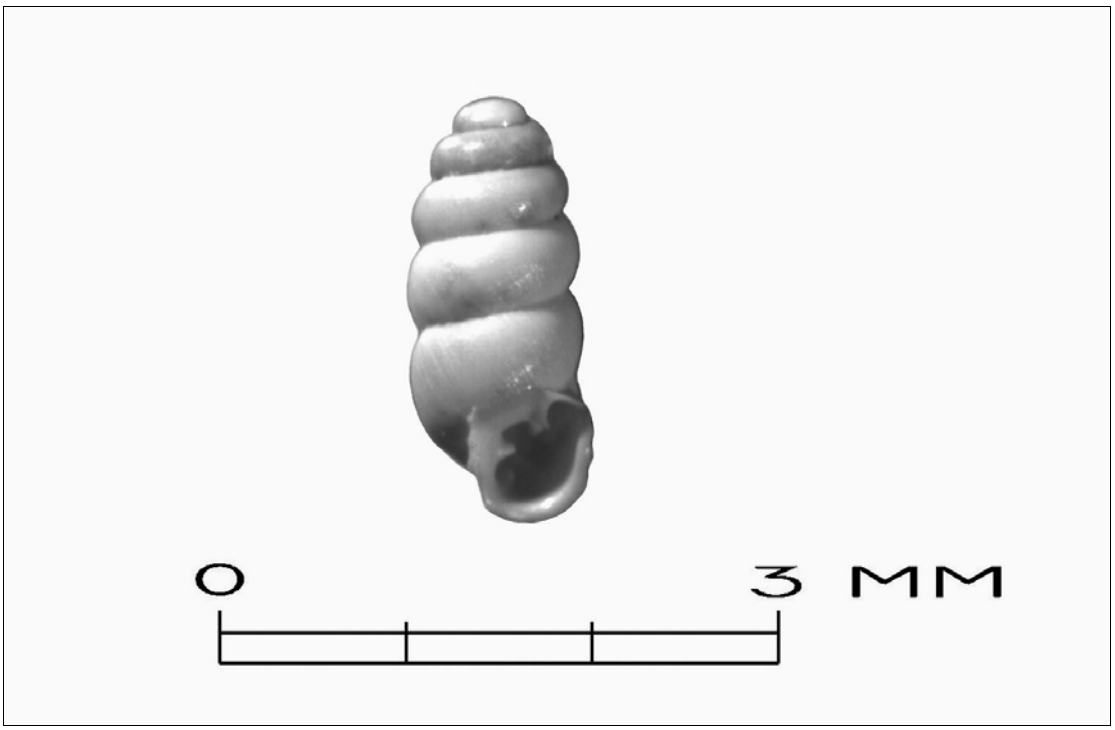


Figure 8.34. *Gastrocopta pellucida*. N109 E96 (92.85-92.80 M), lot B-128.

In the bench deposits, *Gastrocopta pellucida* is regarded as a drought-tolerant, eurytopic species, possibly originating in open, grassy areas above the floodplain. It is present at many of the same sites yielding *G. contracta*, such as Wilson-Leonard, the Mustang Branch site, 41 WM 118, the Anthon site, the Buckhollow site, various sites at Palmetto Bend Reservoir (Neck 1981c), 41 MM 340 and 341, 41 CC 112, the Gaulding site, and the Denton Creek site. It is also present at the Smith Creek Bridge site (Brown 2002:257), the Richard Beene site (Neck 1992:Table 2), Lubbock Lake, the Rex Rodgers

site, Lake Theo (Neck 1978:94), Winston's Cave in Bexar County (Hudler 2000:Table 4-14) and the Domebo site (Cheatum and Allen 1966:39) in Oklahoma.

Gastrocopta pentodon, GPEN

Matrix columns: 1 specimen
1/4-inch screen sample: none
Body size: Microsnail, maximum height 1.5-1.8 mm (Cheatum and Fullington 1973:18)

A single example of this small, rather undistinctive *Gastrocopta* species was found in the N110 E102 matrix column at 92.50-92.45 m. It is similar to *Gastrocopta tappaniana* (a wet-ground species) and can be confused with it (see discussion in Metcalf and Smartt 1997:29). According to Cheatum and Fullington (1973:20), it is "a snail of well-drained woodland areas and of meadows associated with sparse vegetation, Leaf litter and other objects serve as cover." It is widely distributed through the Trans-Pecos and eastern part of the state and occurs widely as a Pleistocene fossil. It was uncommon in the Southern Plains Gastropod Survey, occurring in riparian woodland at the east end of the transect (density, 51 per square meter). Beyond Texas, it occurs widely in the eastern US (Hubricht 1985:Map 61) and into New Mexico and possibly Arizona (?), and southward at least as far as Nicaragua (López and Pérez 1998). Hubricht (1985:9) says it is "a calciphile. Usually found in upland woods in rather dry situations, but is sometimes found in low, wet places with *G. tappaniana*." This species was also very common in Theler's (1997:Table 4) inventory of hill prairies in Wisconsin. Coney and others (1982:83) found it inversely correlated with soil moisture.

The single specimen from the bench deposits can be regarded as a eurytopic, dry woodland or grassland indicator. Examples have been found at the Aubrey site, Lubbock Lake, Rex Rodgers, the Perry site (Fullington 1987:Table 4-9), 34 CD 257 (Fullington

and Fullington 1982a), the Domebo, Burnham, and Hajny sites (Branson 1992:101) in Oklahoma, as well as some sites in Mississippi (Peacock and Melsheimer 2003). Paleontological occurrences include the Ben Franklin fauna in Delta County (Cheatum and Allen 1963:175), the Wood Pit Pond locality on the Trinity River (Slaughter et al. 1962:46-47) and a locality near Sattler in Comal County, reported by Hubricht (1962:1).

Gastrocopta procera (Fig. 8.35), GPRO

Matrix columns: 27 specimens
1/4-inch screen sample: 2 fortuitously recovered specimens
Body size: Microsnail, maximum height 2.3-3.0 mm, average 2.4 mm (Cheatum and Fullington 1973:19-20); 2.3-2.9 mm (Logsdon 1967:50-51)

There are 23 specimens of this species scattered through various levels of the N109 E103 matrix column, perhaps slightly more common in the upper levels. The N110 E102 matrix column has only four specimens. The widespread but spotty geographic distribution of *Gastrocopta procera* is similar to that of *G. pentodon*, both in Texas and across the eastern part of the US. According to Cheatum and Fullington (1973:20), "this species occurs in open as well as woodland areas and is unusually more abundant in the latter. It is frequently found under limestone rock on sloping hillsides with sparse trees and shrubs." Hubricht (1985:9) labels it "a calciphile. Usually found on rather dry ground with sparse vegetation. Frequently found with *Pupoides albilabris*." Logsdon (1967:50-51) found it in woodland debris, leaves in and around rotting logs. In Kansas, Basch, Bainer and Wilhm (1961:193) noted "It seems to be able to survive more adverse conditions than many other gastropods in the state. Leonard and Goble… believe that the success of this species in Kansas is due to its ability to withstand periods of drought and high temperature. It favors hillsides and shuns extremely moist situations. Favorable habitats include timbered areas, both in upland and floodplain situations, as well as

grasslands… and it is frequently found beneath leaves and about old logs. Other sources (for example Metcalf 1962:288) confirm that *G. procera* can be found in both riparian and dry upland, grassy and wooded habitats. In the Southern Plains Gastropod Survey, this was the second most common species, and almost 4800 specimens were collected. It was abundant in rock ledges and toeslopes. Wyckoff, Theler and Carter (1997:32) believe that it is found only in areas with at least 160 frost-free days, but it occurs as far north as Wyoming, South Dakota, and Iowa (Reigle 1963).

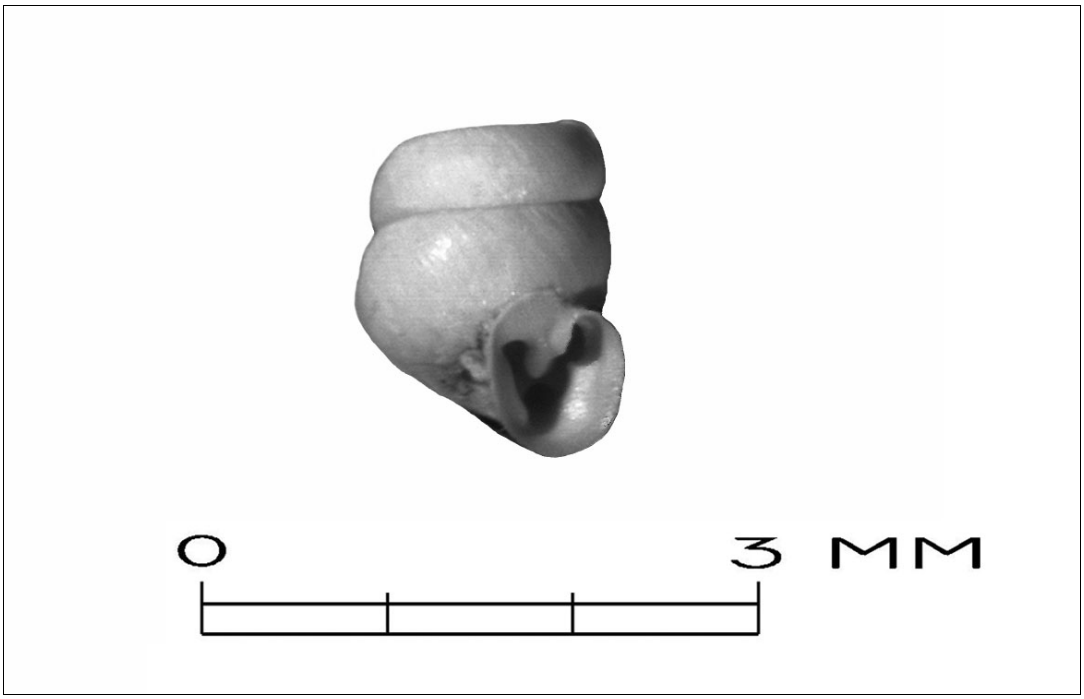


Figure 8.35. *Gastrocopta procera* (?) Basal Fragment. N109 E103 (92.85-92.80 m).

In the bench deposits, this snail is interpreted as a eurytopic, arid-tolerant, dry woodland or grassland indicator, similar to *G. pellucida* and *G. pentodon*. It has been recovered at a wide variety of archeological sites, including the Aubrey site, Lubbock Lake, Rex Rodgers, Lake Theo (Neck 1978:94), 41 CC 112 in Concho County (Treece

1992:Table 15), the Denton Creek site, the Anthon site, the Buckhollow site, the Mustang Branch site, the Wilson-Leonard site, Kenyon Rockshelter, the Richard Beene site, Winston's Cave (Hudler 2000:Table 4-14), the Sleeper site (Neck 1991:Tables 32, 33), 34 CD 257 (Fullington and Fullington 1982a), the Burnham site in Oklahoma, as well as some sites in Mississippi (Peacock and Melsheimer 2003).

Gastrocopta tappaniana, GTAP

Matrix columns: 1 specimen
1/4-inch screen sample: none
Body size: Microsnail, average height 1.9 mm (Cheatum and Fullington 1973:23); 1.5-2.5 mm (Leonard 1959:176), 1.7-2.2 mm (Wu and Jones 1978:201)

A single example of this extirpated (?) mesic-adapted species was recovered from the N109 E103 matrix column (92.45-92.40 m). There are records of shells scattered widely across the state (including Brooks County and Comal County) but according to Cheatum and Fullington (1973:23) living specimens have not been recovered in Texas. Beyond Texas, the distribution is much the same as for the other low-density species of *Gastrocopta* – widely scattered but spotty across the eastern and central US (Hubricht 1985:Map). According to Cheatum and Fullington (1973:23), "Its preferred habitat seems to be on woodland slopes adjacent to streams or other bodies of water. Unlike *G. pentodon* it is usually associated with moist areas." Hubricht (1985:9) says "A calciphile. Usually found in wet places, margins of ponds, floodplains of streams, and marshes. In the southeastern United States, it is found on the undersides of palmetto leaves." Leonard (1959:177) says "This snail is found beneath wood, logs and similar debris in moist places, especially on floodplains and in moist upland forested areas." Basch, Bainer and Wilhm (1961:193) collected it under rocks around a spring and in riparian woodland in Kansas. Neck (1994e:147) lists "protected areas in canyon woodlands." Although this

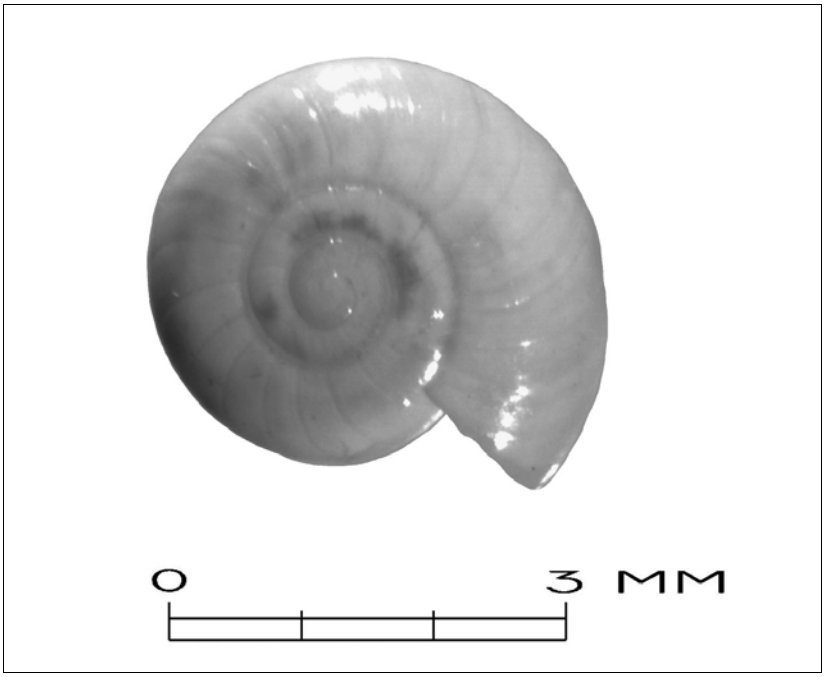
snail could perhaps have been classified as amphibious, I have listed it as terrestrial, and for the bench deposits, the single known example is considered a wet floodplain indicator.

This species seems to be fairly uncommon in the archeological record. Examples are reported from the Clovis and Plainview sites (Drake 1975:225), Aubrey site, Rex Rodgers, the Denton Creek site, 34 CD 257 (Fullington and Fullington 1982a) and the Burnham site in Oklahoma, as well as a protohistoric site in Mississippi (Peacock and Melsheimer 2003) and the Hudson-Meng site in Nebraska (Wu and Jones 1978200-201).. It also occurs in the paleontological record (Allen and Cheatum 1961; Branson, Taylor and Taylor 1962; Schultz and Cheatum 1970, Slaughter and Thurmond 1965).

Glyphyalinia umbilicata (Fig. 8.36), GLYU

Matrix columns: 236 specimens
1/4-inch screen sample: 167
Body size: Large microsnail, diameter 4.7-7.1 mm (Burch 1962:101, as *Retinella indentata*); 5.0-7.1 mm (Pilsbry 1946:291, as *Retinella indentata paucilirata*); 2.3-3.0 mm (Logsdon 1967:63, as *Retinella indentata paucilirata*)

Both the taxonomy and identification of this common, small, zonitid snail are very obscure. For many years, the species was included as *Retinella indentata* or *Retinella indentata paucilirata* in the subgenus Glyphyalinia (Pilsbry 1946:288), but Hubricht (1976:105-106) clearly recognizes *Glyphyalinia umbilicata* as a distinct, valid species, and Raymond Neck identified all of these specimens from the matrix columns as *Glyphyalinia umbilicata*. The name *Glyphyalinia indentata* may also have been applied. In nearly all the older literature, such as Leonard (1959:113-14), the species is listed as *Retinella indentata paucilirata.*



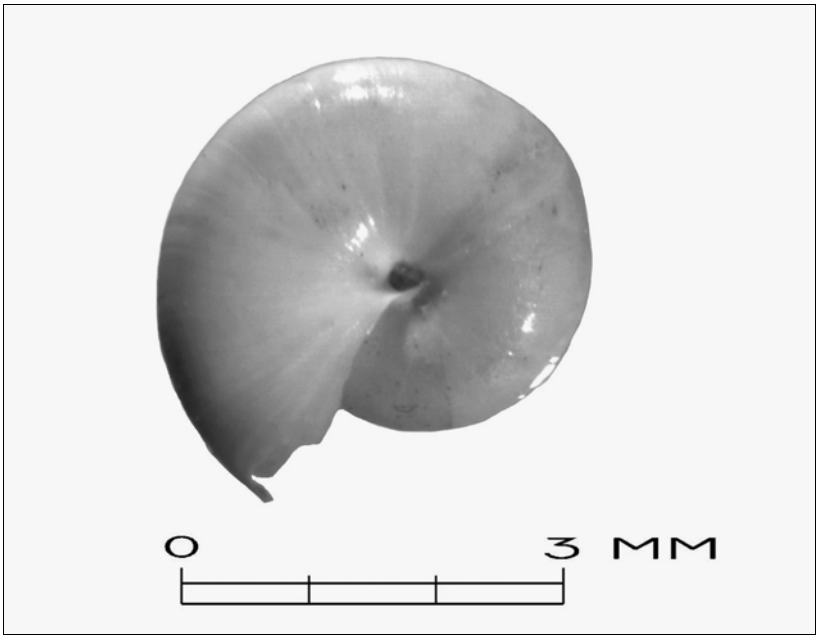


Figure 8.36. *Glyphyalinia umbilicata*. *Top*, apical view; *bottom*, umbilical view. N112 E97 (93.14-92.75 m), Lot B-111.

To compound the situation, the shell is fairly nondescript and can easily be confused with other small discoidal species known to be present at the site, such as *Zonitoides arboreus*, *Hawaiia minuscula*, or perhaps juvenile *Mesomphix friabilis*. In addition, there are three specimens in the 1/4-inch screen sample that seem to fit the description of *Glyphyalinia roemeri* better, and in examining lots of shells from Berger Bluff, there is always the possibility that previously unrecognized genera such as *Nesovitrea* or *Retinella* might be found. The key diagnostic characters for *Glyphyalinia umbilicata* at Berger Bluff are the presence of faint radial indented "spokes" (hence the name *indentata*) on the exterior shell surface and a very narrow umbilicus. *Zonitoides arboreus* has a wider umbilicus and lacks the radial lines.

As mapped by Hubricht (1985:Map 231), the species has an odd distribution confined mostly to the eastern part of Texas (see also McGee 1965:76) and to Florida, and a small stretch of the Atlantic coastal plain to the north. However, it is also reported in Utah by Oliver and Bosworth (1999:213-214), and Pilsbry (1946:291, as *R. indentata paucilirata*) reports it in Indiana, Kentucky, Tennessee, Alabama, Arkansas, Louisiana, Mississippi, Missouri, Oklahoma, New Mexico, Arizona, Durango, Jalisco, Morelos, Michoacan, and Puebla as well as Texas. Most of the published habitat preference information is listed under the *Retinella indentata* rubric. The species is "usually found under logs and leaf litter in the woods bordering streams" (Hubricht 1985:25), "from rotten logs, forest debris, and under leaf litter" (Logsdon 1967:63), "collected from moist areas only, with the largest number found under moist leaf mold in a hedgerow… This species was often found under or on rotting wood or in moist leaf litter" (Basch, Bainer and Wilhm 1961:196, as *R. indentata*). According to Neck (1981c:124), it occurs in both woodland and grassland where abundant cover is available. Only 8 specimens were found

in the Preiss Ranch drift sample (Table 8.9). In the bench deposits, this species is considered a mesic deciduous woodland indicator, although it apparently persists in some rather arid parts of Mexico and the western US. Specimens occur throughout the section, but are especially abundant in three zones: at the top of the section, in stratum 2B, and in stratum 2A.

Unfortunately, the persistent taxonomic confusion in the literature makes it difficult to discern exactly what has been recovered archeologically. *Glyphyalinia umbilicata* is reported from the Mustang Branch site, the Wilson-Leonard site, Kenyon Rockshelter, Bering Sinkhole (Bement 1994:Table 7), the Anthon site, the Buckhollow site, 41 CC 112, 41 TV 368 (Neck 1981b), 41 JK 66, 41 JK 74, and 41 JK 78 (Neck 1981c:Tables 11-5 to 11-8), 41 WM 312 (Voellinger and Gearhart 1987:Table 28), the Gaulding site and 34 CD 257 (both as *Glyphyalinia indentata paucilirata*). A few examples (measuring 2.4-6.3 mm in diameter) were found at the Smith Creek Bridge site (Brown 2002:Table 73).

Glyphyalinia indentata is reported from the Aubrey site, Rex Rodgers, the Denton Creek site, and the Burnham site. *Retinella indentata* is reported from 41 WM 118, the Berclair Terrace in Bee County (Conkin and Conkin 1962:348) and the Domebo site in Oklahoma. Whether all of these reported examples are separate species or the same is unclear.

Glyphyalinia cf. *G. roemeri* (?) (Fig. 8.37), GLYR

Matrix columns: none
1/4-inch screen sample: 1 specimen
Body size: Microsnail, diameter 4 mm (Pilsbry 1946:278, as *Retinella roemeri*)

A single specimen fortuitously recovered from the 1/4-inch screen in N109 E103 (92.85-92.80 m, lot B-5) fits the definition of *Glyphyalinia roemeri*. It has a diameter of 3.3 mm, height of about 1.4 mm, and an umbilicus 0.7 mm wide. It differs from *G. umbilicata* by having a much wider, well-defined umbilicus and lacking the radial impressed "spokes" on the exterior surface. It differs from *Zonitoides arboreus* in having a slightly wider umbilicus and a shallower profile. *Glyphyalinia roemeri* is an Edward Plateau species (Hubricht 1985:Map 224) that is not reported for the coastal plain (except for occurrences in the counties of De Witt, Refugio and Nueces mapped by McGee 1965:25), so either I have misidentified the specimen, or the range of the species was greater at the end of the Pleistocene. According to Hubricht (9185:23-24), the species is "found under rocks and in moist leaves on wooded talus slopes, in ravines, and in caves." In Travis County, Neck (1994e:149) lists the preferred habitat as caves and wet areas. Archeological specimens have been reported from Kenyon Rockshelter and from 41 CC 112 in Concho County (Treece 1992:Table 15), which is also outside the documented range of the species. It is also reported (as *Retinella roemeri*) from 41 CH 56 (Weinstein and Whelan 1987:Table 4-14), again outside its documented range.

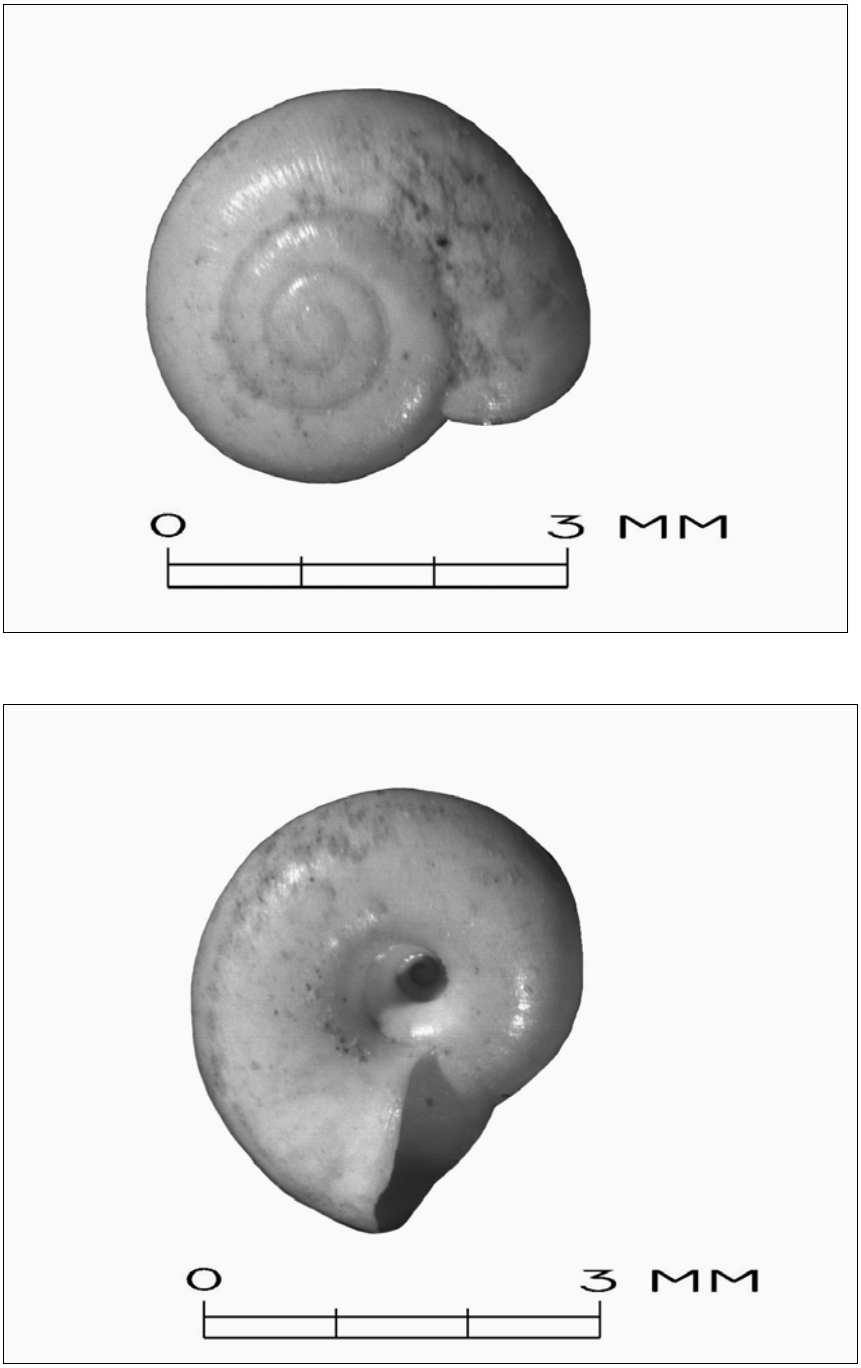


Figure 8.37. *Glyphyalinia* cf. *G. roemeri* (?). *Top*, apical view; *bottom*, umbilical view. N109 E103 (92.85-92.80 m), Lot B-5.

Hawaiia minuscula, HAWM

Matrix columns: 3 specimens
1/4-inch screen sample: none
Body size: Microsnail, diameter 2.0-2.8 mm (Burch 1962:106), 0.4-2.7 mm (Branson 1967:295), 2.0-2.5 mm (Leonard 1959:120)

This small, discoidal snail is very similar in appearance to *Helicodiscus singleyanus* and might easily be confused with it. Although it often occurs in large populations in contemporary snail faunas (Branson found 1080 specimens at Welder Refuge), only three specimens were found in the matrix columns from the bench deposits. Hubricht (1985:29) characterizes it as "a species of bare ground. I have never found it in leaf litter." In contrast, Coney and others (1982:90) found it positively associated with leaf litter (and inversely associated with soil moisture) in Tennessee. Leonard (1959:120) says it is "found under logs, sticks, stones and in clumps of grass in both floodplain and upland situations." Leonard and Goble (1952:1042) remark "although this small snail prefers a woodland environment, it is able to survive under arid conditions…. it was abundant only along the banks of the small stream (SC). Here, it was in the loose moist soil under a light layer of decaying vegetation. Other habitats included: under leaves in an oak-elm area (SE); among grass roots (SH); and under decaying longs on the north facing slope." This was the fourth most common species in the Southern Plains Gastropod Survey, where it was found in rock ledges and under downed wood in riparian woodland. It also showed up in fairly high abundances in Nekola's (2002:Table 2) study of grasslands in Minnesota, Iowa, and Wisconsin. It occurs throughout the continent from Alaska and Maine to Costa Rica, as well as the Caribbean, westward to Arizona (Pilsbry 1946:421). It is common in New Mexico (Metcalf and Smartt 1997:51)

and Texas (McGee 1965:80). According to Metcalf (1984:61), it has broad ecological tolerances.

The species is reported from a wide range of archeological sites, including the Aubrey site, Rex Rodgers, Lubbock Lake, Lake Theo, the Sulphur Springs site in Martin County (Neck 1994d), Winston's Cave, 41 WM 118 (Amaral and Witter 1973), the Anthon site (Neck 2002:260), the Buckhollow site (Neck 1994c), 41 MM 340 and 341, the Gaulding site, 41 CH 56 in Chambers County (Weinstein and Whelan 1987:Table 4-14), the Denton Creek site, 41 FT 193, 41 DT 59, 34 CD 257, the Burnham and Hajny Mammoth sites (Oklahoma) and Lehner and Murray Springs sites (Arizona; Bequaert and Miller 1973:145). It also appears at various undated paleontological sites reported by Hubricht (1962).

The few Berger Bluff specimens are interpreted as indicators of open grassland or well-drained, open woodland.

Helicodiscus singleyanus (Fig. 8.38), HELS

Matrix columns: 2526
1/4-inch screen sample: 272 fortuitously recovered specimens
Body size: Microsnail, diameter 2.0-3.0 mm (Burch 1962:79), 1.1, 2.1 mm (Branson 1967:296), 2.5 mm (Leonard 1959:133), 2.4 mm (Pilsbry 1948:636)

Remarkably, this very small, rather nondescript discoidal snail is the single most abundant species in the bench deposits, regardless of body size. Because it is small, somewhat delicate and thin-walled, its abundance cannot be due to exceptional durability. There is also no compelling evidence that it is especially well adapted to microhabitats at the site. I suspect, although I can find no data on reproductive rates, that it is probably a

prolific breeder (perhaps an r-selected species) and this may account for its consistent abundance. The literature does not support this speculation, however; where recovery rates for contemporary specimens are reported, they are low to moderate. Perhaps the species is hardy and can persist in dry conditions, but becomes much more numerous when allowed by moist habitats. It accounts for almost 18% of the terrestrial snails in the Preiss Ranch drift sample (Table 8.8). This species has gone largely unnoticed in the biological, if not the archeological literature, and it is difficult to discover anything definitive about its properties or habitat preferences. The distribution map published by Hubricht (1985:179) is largely blank, not because of low population densities, but because of inadequate reporting.

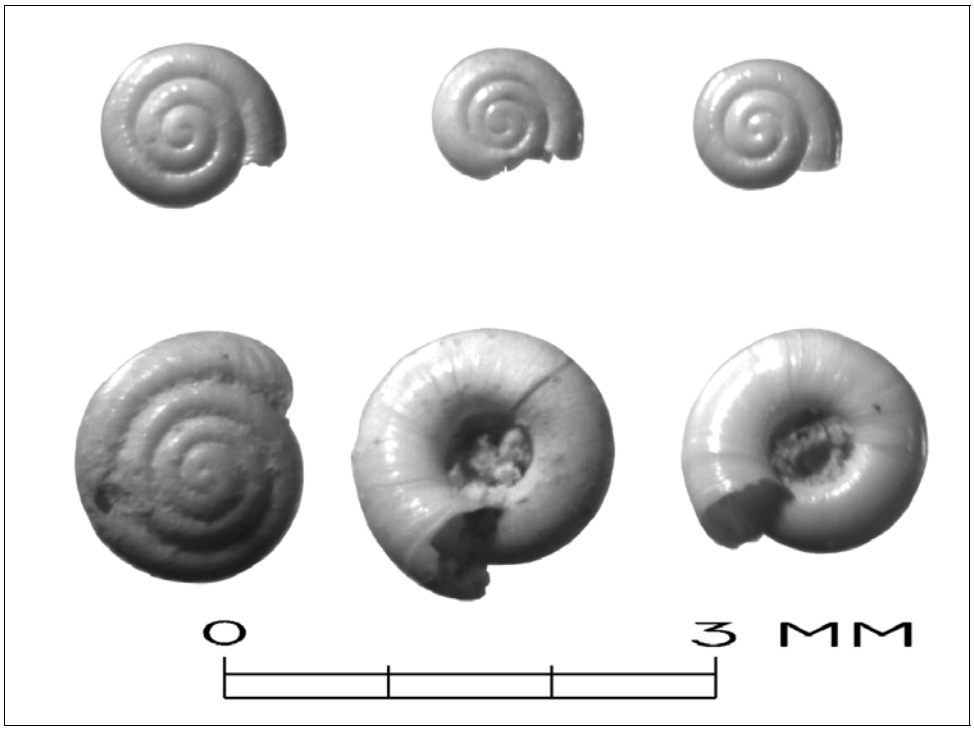


Figure 8.38. *Helicodiscus singleyanus*. Selection of six different-sized specimens from a lot of 29 in N109 E96 ((2.85-92.80 m), Lot B-128. All views are apical except bottom right two specimens.

Hubricht (1985:22) says only “a species of open, grassy places, roadsides, along railroads, and meadows.” This species was fairly common and moderately abundant in the Southern Plains Gastropod Survey, occurring with a density of 83 individuals per square meter on a mesa top. It was also found in rock ledges and riparian woodlands, and in low numbers on toeslopes and in grasslands (Wyckoff, Theler and Carter 1997:36). La Rocque (1970:685) says “damp to dry habitat, damp, protected places or relatively dry, exposed habitats. This species is more tolerant of drouth than others and requires little cover.” Basch, Bainer and Wilhm (1961:195) collected only five specimens, remarking “It seems probable that *H. singleyanus* lives among grass roots, even on exposed slopes that become hot and dry during the summer… it is usually found under forest debris or among leaves or piles of washed materials….” The species is reported in Theler’s (1997:Table 3) study of Wisconsin hill prairies and Nekola’s (2002) study of grasslands in Minnesota, Iowa, and Wisconsin, but in fairly low densities. Metcalf (1984:61) found it widespread but not abundant. Fullington 91978:112) says “it is assumed that in this area (including Texas) that it can tolerate drier conditions by burrowing under grass roots…. a relatively common fossil species in Texas but some records may be based on *H. minuscula* with which it may easily be confused.” In New Mexico, it occurs under stones, rock talus, or leaf litter and is a common fossil in Quaternary floodplains (Metcalf and Smartt 1997:40).

In the bench deposits, *Helicodiscus singleyanus* is presumed to be a eurytopic, drought-resistant snail capable of surviving in fairly open, well-drained habitats. In the Berger Bluff matrix columns, about 34% of the specimens floated to the surface when the samples were processed. This species is abundantly distributed throughout the bench

deposits. Every sample in both matrix columns was well supplied with specimens, especially the strata above stratum 2A.

Archeological occurrences include the Aubrey site, Rex Rodgers, Lubbock Lake, Mustang Branch, Wilson-Leonard, Richard Beene, Anthon, Buckhollow, Sleeper site, Bering Sinkhole (Bement 1994:Table 7), 41 FS 6 (Wulfkuhle 1986:405), 41 CH 56 in Chambers County (Weinstein and Whelan 1987:Table 4-14), Swan Lake (Neck 1987c), Denton Creek, Kenyon Rockshelter, 41 TV 368, 41 WM 312 (Voellinger and Gearhart 1987:Table 28), 41 FT 193, 41 CC 112, 34 CD 257, and the Domebo and Burnham sites. At Burnham, it is one of the most abundant terrestrial species.

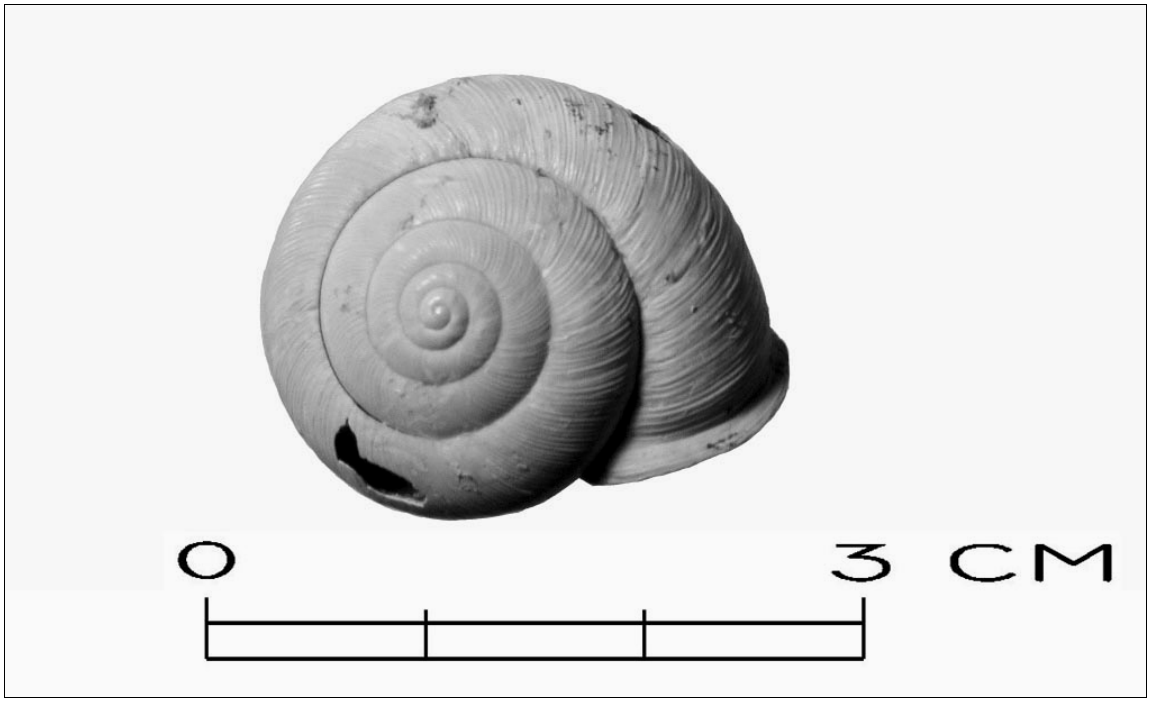
Mesodon cf. *M. roemeri* (Figs. 8.39, 8.40), MROE

Matrix columns: none
1/4-inch screen sample: 8 specimens
Body size: Large-bodied, diameter 20.0-28.0 mm (Cheatum and Fullington 1971:30); 18.0-24.0 (Logsdon 1976:76-77), 18.0-21.5 (McClure 1970:Table 1)

As mapped by Cheatum and Fullington (1971:Fig. 9), the present range of *Mesodon roemeri* lies in central, east-central, and north Texas, with the closest reported occurrences in Wharton County and Lavaca County. Likewise, Raymond Neck did not find any examples of the species in his studies of the N109 E103 and N110 E102 matrix columns. However, of the 90 specimens from the 1/4-inch screen identifiable as *Mesodon*, eight (from N111 E101 and N112 E97) seem to fit the definition of *Mesodon roemeri* better than *Mesodon thyroidus* and have tentatively been classified accordingly. These are larger in diameter and relatively shallower in profile than *M. thyroidus*. Although there are few measurable specimens to compare (only four *M. thyroidus* and six *M. roemeri*), the differences seem definite. Specimens classed as *M. roemeri* have a

diameter of 22.08 ± 1.93 mm (range, 19.20-24.90 mm) and a height/diameter ratio of 0.6013 ± 0.0237, usually with 5 or 5.5 whorls. Specimens classed as *M. thyroidus* have a diameter of 21.44 ± 1.66 mm (range, 19.00-23.50 mm) and a height/diameter ratio of 0.7084 ± 0.2360, usually with 4.25 whorls. The shells of this genus are quite fragile, and both species of *Mesodon* are probably greatly underrepresented in the counts.

For habitat preference, Cheatum and Fullington (1971:31) say "Occurs more commonly in dense woodlands along water; or sometimes thriving colonies may be found living under humus in sparsely-wooded slopes." Hubricht (1985:44) says "Found under rocks, leaf litter, and logs on wooded slopes near streams." Logsdon (1967:76) found it in decaying log debris in wooded floodplains, and Neck (1996) found it in similar habitats in Meridian State Park. The autecology of the species was studied experimentally by McClure, who compared *Mesodon roemeri* with *Rabdotus dealbatus* from the same collection area. She found *M. roemeri* is active 50-60% of the year, has lower mortality and reproductive rates than *Rabdotus*, and is adapted to a wooded habitat that is less variable, more humid, and cooler than the grassland habitat preferred by *Rabdotus*. This species is much less tolerant of high temperatures than *Rabdotus dealbatus*, and high mortality occurs in hot, dry conditions (McClure 1970:33). She estimates that *M. roemeri* become mature at 1.5-2.0 years of age and have an average lifespan of three years or more. She also observes that "*Mesodon* will eat nearly every kind of food offered but seems to prefer fungi if they are available in the field. Often I have observed this species literally packed inside and under mushrooms and puffballs of various kinds…. The preferred habitat of *Mesodon roemeri* is under and on the bark of moist, decaying fallen logs. In the woods hundreds could be collected in a few minutes from beneath the bark of an appropriately decayed log." (McClure 1970:50-51).



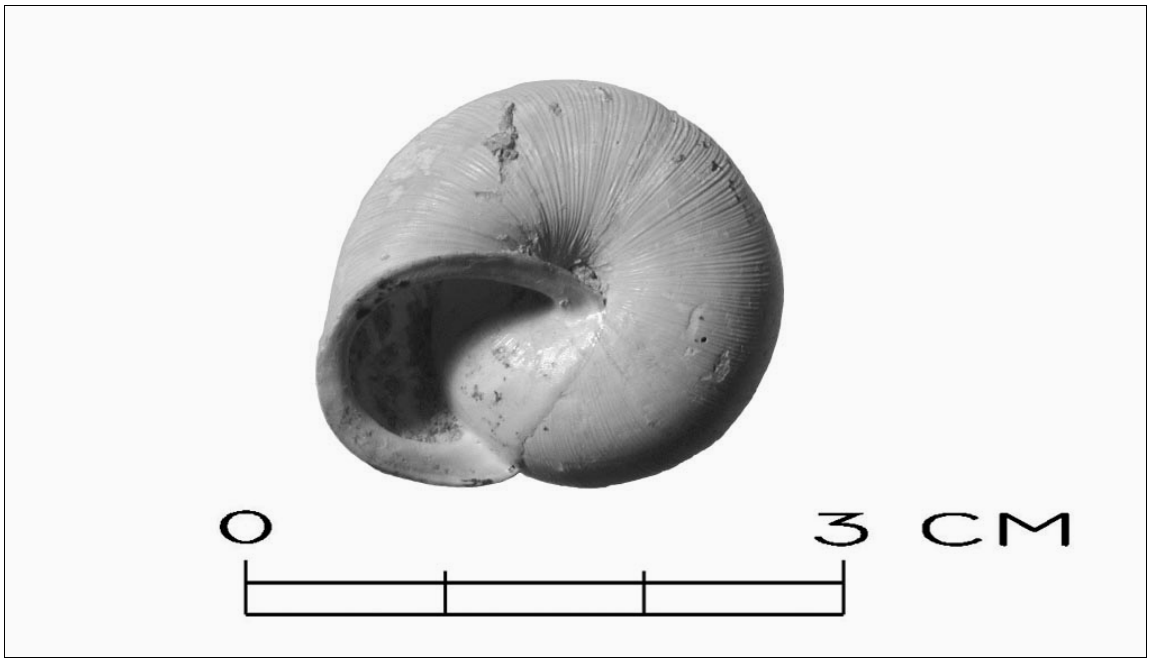


Figure 8.39. *Mesodon* cf. *M. roemeri* (?). *Top*, apical view; *bottom*, umbilical view. N112 E97 (93.14-92.75 m), Lot B-112. Also see next figure.

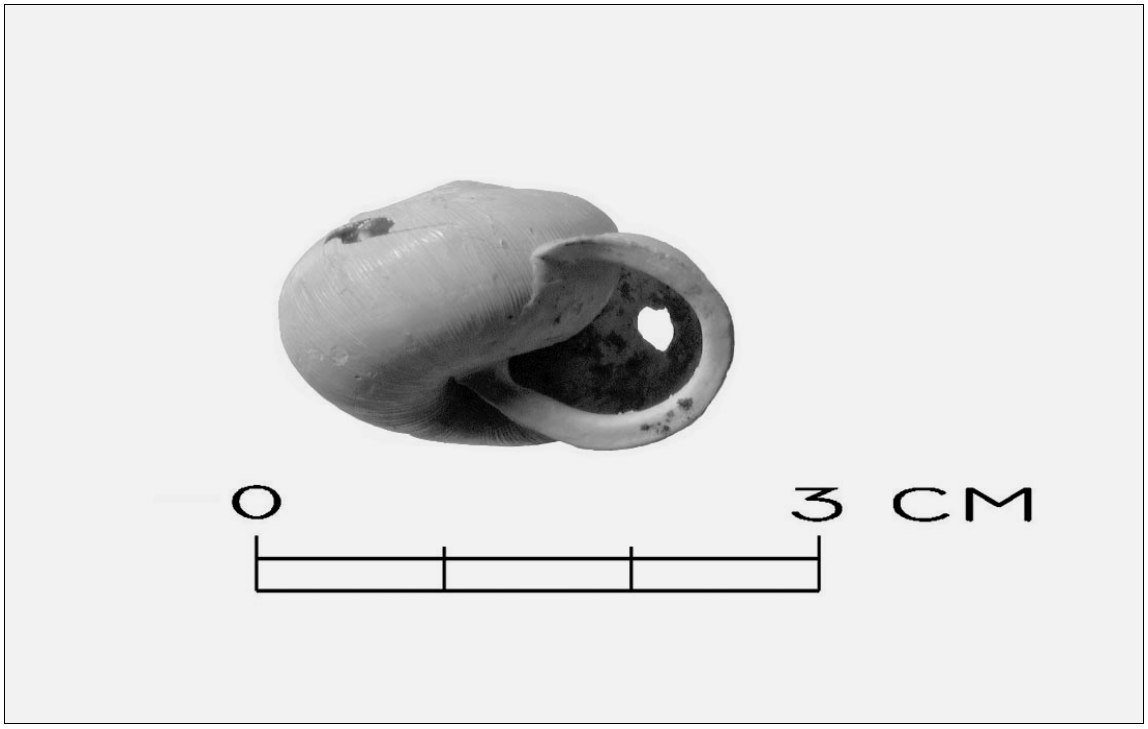


Figure 8.40. *Mesodon* cf. *M. roemeri* (?), Adaxial View. Same specimen shown in Figure 8.39.

A census of snails in measured quadrats yielded a density of about 3.7 *Mesodon roemeri* per square meter in a wooded area (and about 1.6/m^2 in the entire survey area; Randolph 1973:955).

Archeological occurrences include the Sleeper site, Bessie Kruze site (Gardner 2000:222), the McDonald site (Neck 1987d:Table III.1), Bear Creek Shelter (Lynott 1978:70), 41 WM 312, and 41 BT 37 (Malof 2004:51); and the Potters' Pleasure site, Five Goat Shelter, Stone Rockshelter, L. E. Robertson Shelter, the Dam site, Windy Shelter and Opilionid Shelter, all in the Hog Creek project (Kirby and Reeder 1980). In

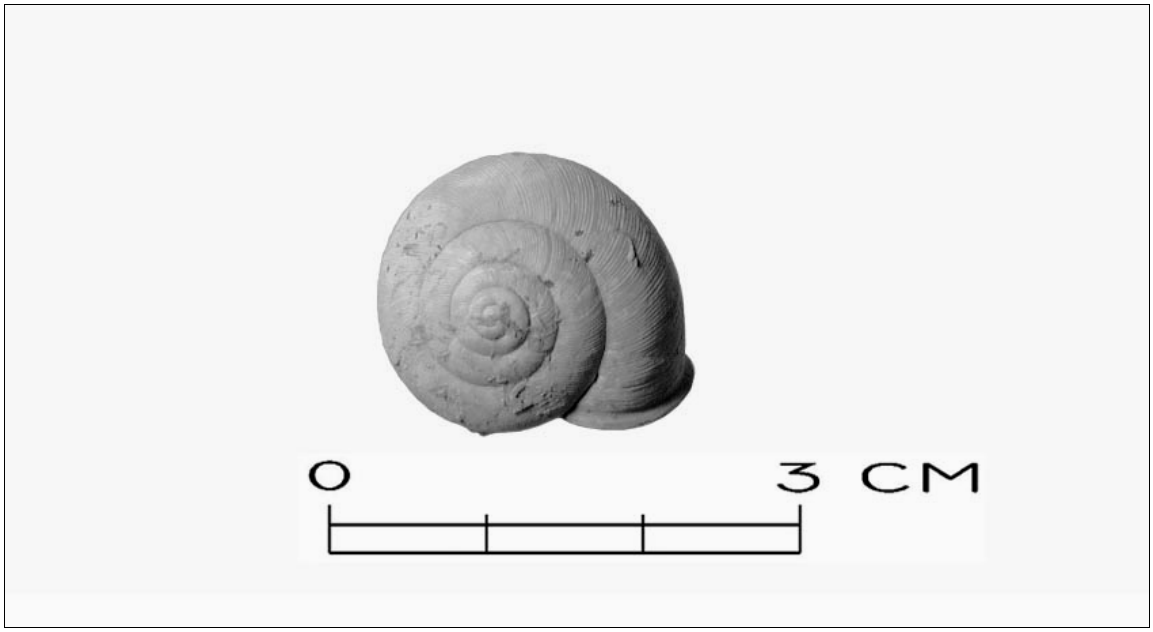
the bench deposits, this species is interpreted as an indicator of heavy, closed-canopy deciduous woodland.

Mesodon thyroidus (Figs. 8.41, 8.42), MTHY

Matrix columns: 2 specimens
1/4-inch screen sample: 10 specimens (plus 72 fragmentary *Mesodon* sp.)
Body size: Large-bodied, average diameter 20 mm, height 12-13 mm (Cheatum and Fullington 1971:29); diameter 20.7-28.3 mm (Logsdon 1967:75-76); 18.5-24.5 mm (Pilsbry 1940:709), 17.5-22.1 mm (Leonard 1959:87); diameter 17.5-23.0 mm, height 11.0-15.5 mm (Branson 1969:389)

Complete *Mesodon* shells are scarce in the bench deposits owing to postmortem breakage from processes such as sediment compaction and screen damage. In many levels, there are recognizable *Mesodon* shell fragments, but no complete shells. The MNI count of 72 individuals from the 1/4-inch screen could include both *Mesodon roemeri* and *Mesodon thyroidus*, but probably represents mostly the latter. Consequently, I estimate there are far more *M. thyroidus* present than the 12 identifiable individuals listed above. Fragments and complete shells are present throughout strata 2C, 2D, and 3, but are absent below, except for a single fragmentary individual at the 92.15-92.10 level in N109 E103. The exclusion of *Mesodon* from the lower bench strata could be due either to poor shell preservation or to habitat unsuitability.

Only five individuals were complete enough for measurement. These have a mean diameter of 21.44 ± 1.66 mm (range, 19.00-23.50 mm) and a height/diameter ratio of 0.7084 ± 0.2360, usually with 4.25 whorls. Mean height is 15.43 ± 1.17 mm (range, 11.80-15.30 mm).



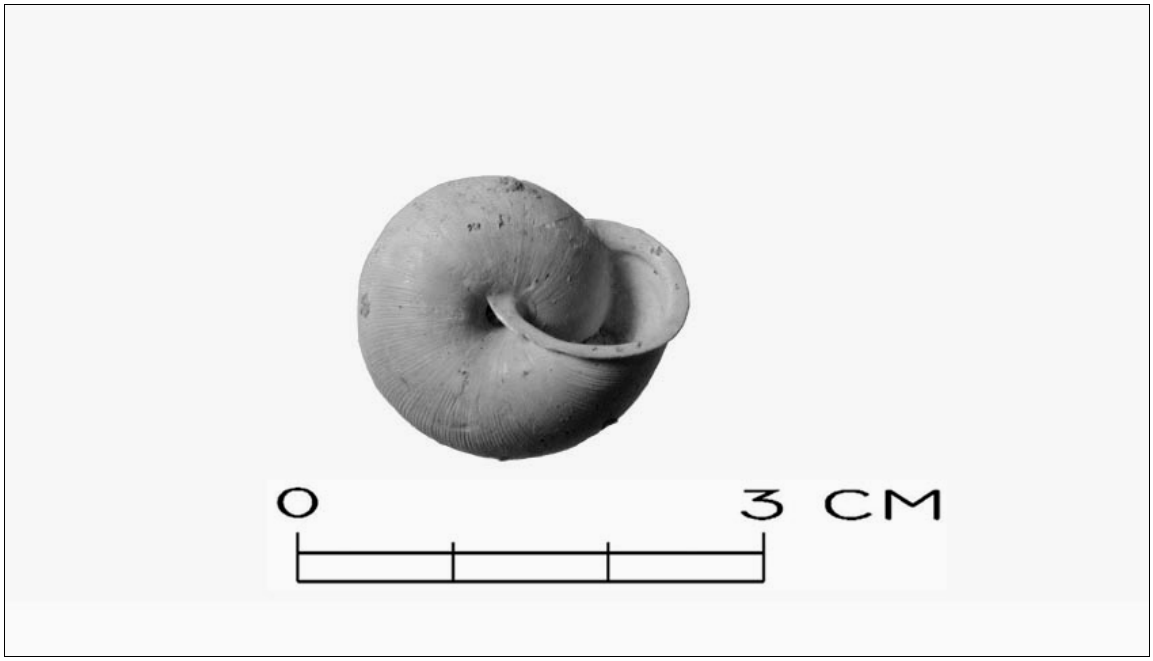


Figure 8.41. *Mesodon thyroidus*. *Top*, apical view; *bottom*, umibilical view. N109 E103 (93.14-92.90 M), Lot B-1.

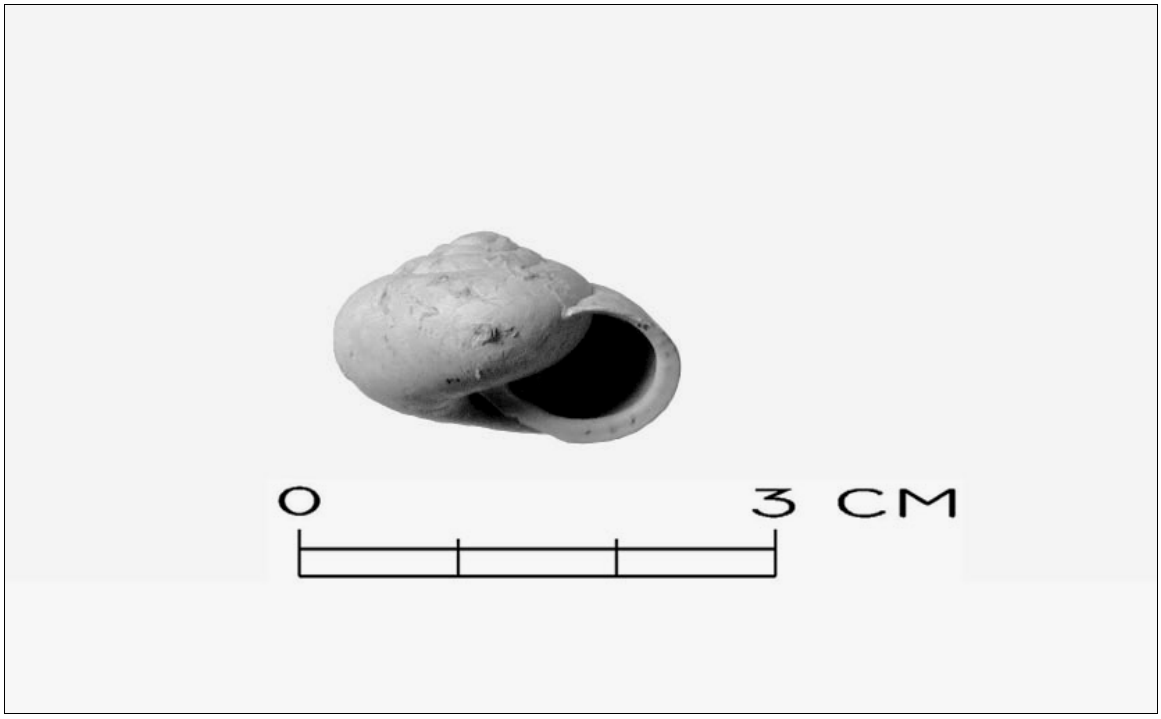


Figure 8.42. *Mesodon thyroidus*, Adaxial View. Same specimen shown in Figure 8.41.

Foster (1936) studied size variation in large samples of *Mesodon* (here the obsolete name *Polygyra thyroides* is used) in Illinois and found considerable local variation in size. Modal sizes for most of his specimens are about 17.5-19.1 mm (Foster 1936:Figs. 1-3, 5).

Mesodon is a well-known and studied large-bodied eastern woodland genus usually associated with leaf litter and rotting logs (Branson and Batch 1970:339). Logsdon (1967:75) says "*Mesodon thyroidus* was collected from logs, moist sticks, flood debris, and damp decaying spots on trees at the Forney site (C), and from logs in the weeded flood plains three miles west of Crandall." There are too many habitat

descriptions to list here. La Rocque (1970:573-574) gives an extensive synopsis; see also Metcalf (1962:283). According to Leonard (1959:90),

> This forest snail is found on and under rotten logs, smaller pieces of wood and in litter. This subspecies seems to be closely associated with floodplains and their margins in Kansas, but has been reported from drier situations in Indiana… and Michigan…. [it is also recorded] from marshy areas, as well as on trees at heights of from 2 to 6 feet above the ground. According to Goodrich and van der Schalie… this species adapts itself well to open fields and gardens.

> The species was recorded by Goodrich and van der Schalie… as feeding on "mildews, slime molds and fungi." According to Pilsbry (1940:710), *Mesodon thyroidus* has been reported feeding chiefly on wood nettles (*Laportia canadensis*) in Illinois, whereas others, studying the species elsewhere, have reported the principal food to be fungi.

According to Blinn (1963:501), the snails ingest log mold and when feeding on angiosperms, usually eat damaged and decaying plant tissue. Decaying logs (usually found in mature deciduous floodplain woodland) seem to be an important microhabitat for this species. *Mesodon thyroidus* also frequently climbs trees, as much as 13 feet above the ground. Blinn found them on ash, elm, linden, hackberry, and willow. It forms an epiphragm and hibernates (in northern Illinois, mostly from November through March) partly buried in the soil and can withstand subfreezing soil temperatures (Blinn 1963:501). Some member of the genus are known to be able to float in water (Webb 1964).

Mesodon thyroidus occurs throughout the eastern US (Hubricht 1985:Map 466), as far north as southern Ontario (Oughton 1948:8) halting near the eastern edge of the Plains, probably due to the lack of woodland. In Texas, it occurs in the eastern third of the state, roughly bounded on the west by the 32-36" rainfall isohyets (Fig. 8.12).

Occasional recent examples of this species, both juvenile and adult, were found during diatom sampling in the Berger Bluff catchment (Table 8.6). In the bench deposits, this species is also interpreted as an indicator of heavy, closed-canopy, mature deciduous woodland with abundant leaf litter and rotting wood. However, it is noteworthy that clustering and ordination studies (discussed later in this chapter) consistently grouped this snail with more arid-adapted species from the bench.

Archeological examples of this species are somewhat sparse: the Aubrey site, 41 DT 59 (Fullington 1995), the Guadalupe Bay site (Fullington 2002a); 41 JK 53, 41 JK 66 and 41 JK 74 (Neck 1981c), 41 FB 199 and 41 FB 200 in Fort Bend County (Zimmerman 1996:Table 8, 9), 41 WL 15 in Waller County (McClure and Neck 1987:Table 1), and the Domebo site (Cheatum and Allen 1966:39) in Oklahoma. At 41 FB 200, one of the features excavated had a concentration of *Mesodon thyroidus*.

Mesomphix friabilis (Figs. 8.43, 8.44), MEZF

Matrix columns: 149 specimens
1/4-inch screen sample: 1021 specimens
Body size: Large-bodied, diameter 21.0-26.3 mm (Pilsbry 1946:328, Burch 1962:92)

Although abundant in the bench deposits, these large, spherical zonitid snails are largely overlooked in the literature. *Mesomphix* is a typically Appalachian genus (Pilsbry 1946:305), but most of the other species in the genus are much better documented. Distribution extends from the central coastal plain of Texas northeastward throughout the Mississippi River basin to Illinois, Indiana, Ohio, and Virginia (Hubricht 1985:Map 239, La Rocque 1970:Fig. 487). It is reported from Goliad State Park (Table 8.5) and from the counties of Victoria (Pilsbry 1946:330), Calhoun, De Witt, and Refugio (McGee 1965:77), but I have seen no contemporary specimens in the Berger Bluff catchment.

According to Hubricht (1985:26), the species is "usually found on floodplains under leaf litter, but sometimes found on river bluffs and in ravines." In Travis County, Neck (1994e:149) lists it from riparian woodlands. Neck also says "*Mesomphix friabilis* is characteristic of mesic woodlands and is often associated with *Anguispira strongylodes*, although *M. friabilis* is able to survive in woodlands which are too xeric for *A. strongylodes*. Cover may be supplied by leaf litter; downed wood is not utilized." However, Amaral and Witter (1973:421) found it under moist rotting logs in the San Gabriel River floodplain. It has a thick shell and is a calciphile species (Riggle 1976:8). In Indiana, it has been found in a cypress swamp (Goodrich and van der Schalie 1944:270). There are several allied species of *Mesomphix* in the eastern US, and they are nearly always found in habitats with leaf litter and decaying wood (cf. Branson and Batch 1970:341-342). Two of these species, *Mesomphix andrewsae and M. subplanus*, have a

density of about 0.15-0.20 individuals per square meter (Stiven 1989:375). One allied species, *Mesomphix cupreus*, is said to be carnivorous, preying on other snails (La Rocque 1970:631-632).

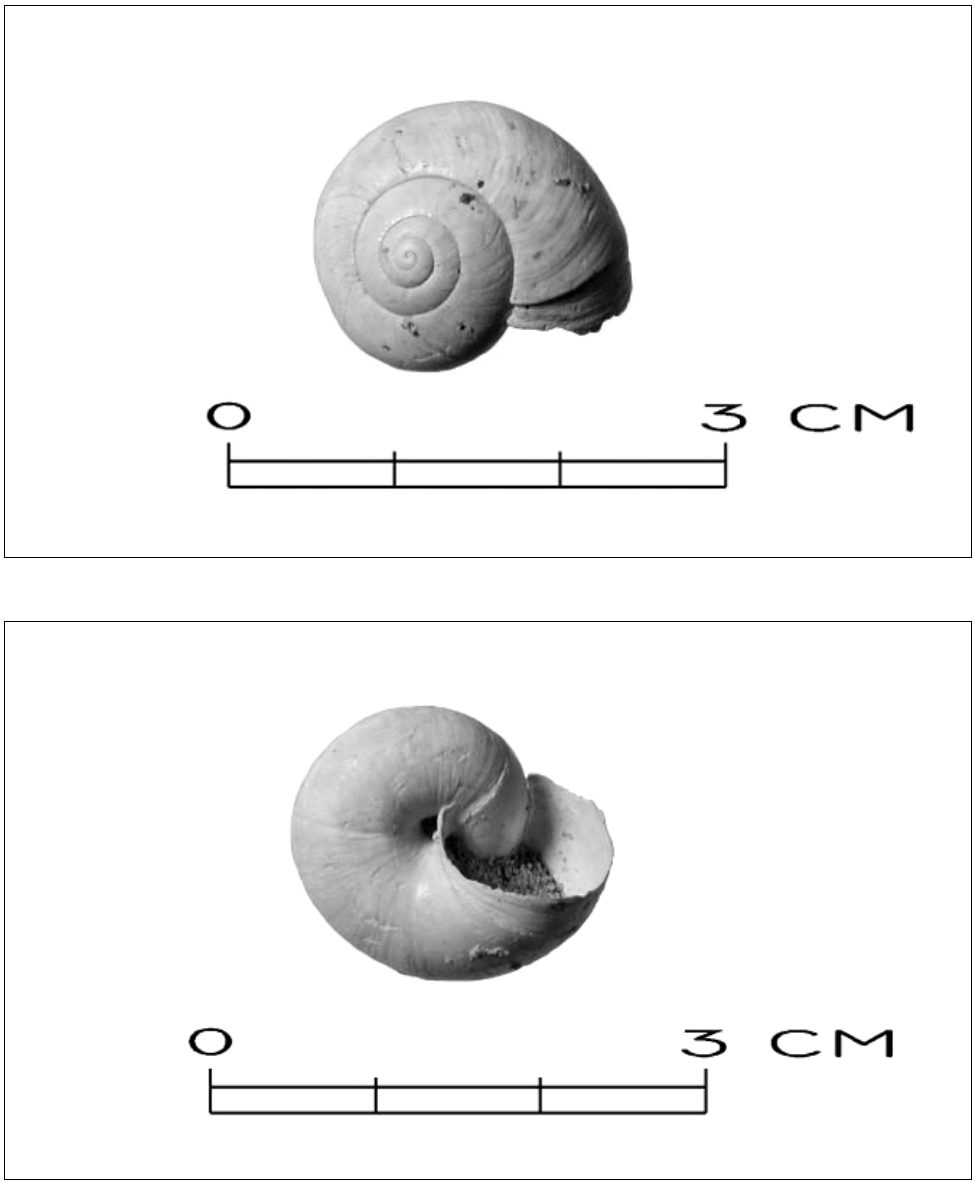


Figure 8.43. *Mesomphix friabilis*. Top, apical view; bottom, umbilical view. Small to medium-sized adult from N109 E103 (92.90-92.85 m), Lot B-3, ¼-inch screen sample. See also Fig. 8.44.

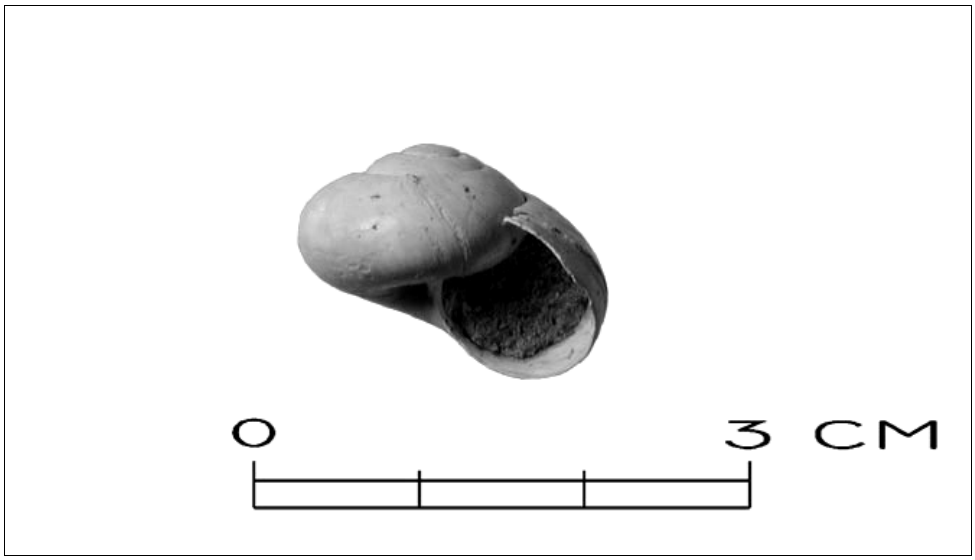


Figure 8.44. *Mesomphix friabilis*, Adaxial View. Same specimen as Fig. 8.43.

In the bench deposits, this species is regarded as another good indicator of mesic deciduous woodland, similar to *Anguispira*, *Euchemotrema*, and *Mesodo*n. Although the shell wall in this species is thick and sturdy, the exterior surface is glossy and the whorls are weakly joined as a result. Collapsed spires are common. The aperture does not have a reinforced lip, so chipped apertures are also common in the bench specimens, and it is impractical to obtain measurements on most specimens, although Amaral and Witter (1973:Fig. 76) measured *Mesomphix friabilis* from 41 WM 118. Archeological examples are known from the Wilson-Leonard site, the Bessie Kruze site, Rice's Crossing, 41 WM 53, 41 WM 124, 41 WM 258, and 41 WM 267 (Fullington and Fullington 1982b), 41 WM 130 (Bond 1978:Table 4), 41 WN 118, 41 WL 15 in Waller County (McClure and Neck 1987:Table 1), 41 JK 66, 41 JK 74, and 41 JK 78 in Jackson County (Neck 1981c). No examples were found at the Smith Creek Bridge site or anywhere in the catchment during diatom sampling.

Oligyra orbiculata (Fig. 8.45), OLIO

Matrix columns: 420 specimens
1/4-inch screen sample: 4067 specimens
Body size: Medium-bodied, diameter 6.1-8.6 mm (Fullington and Pratt 1974:8), 5.0-8.5 mm (Burch 1962:37), 8.1-9.3 mm (Logsdon 1967:79)

This medium-bodied, eurytopic, colonial, operculate snail is the most abundant species recovered from the 1/4-inch screen and the second most abundant species recovered from the matrix columns. It is also probably the most common easily visible species encountered today in most of south and central Texas. It was formerly named *Helicina orbiculata* and appears under that name in older literature. The common subspecies *H. orbiculata tropica* (distinguished by a heavily thickened apertural lip) has been determined to be a morphological variant with no taxonomic value (Strenth and Littleton 2000). With its thick, subspherical shell and teardrop-shaped operculum (Fig. 8.27), this species is well-equipped to limit water loss and is very drought resistant. It is often seen in open, bare to grassy areas that are too xeric for other species. It is a cosmopolitan and resilient species often appearing in large numbers, much like *Helicodiscus singleyanus*.

According to Fullington and Pratt (1974:8),

> *Helicina orbiculata* occurs in localized colonies, usually on limestone, in deciduous or juniper woodlands. In the sandy soils of the Pine-Hardwoods forests in east Texas it is rare and colonies are widely separated. It is… often found in the woodland corridors along prairie streams. It is semi-arboreal, climbing on rocks, shrubs, and the lower parts of tree trunks. It estivates in the open, cemented to rocks and tree trunks during summer dry spells. During the winter it hibernates in the soil at the base of trees and rocks.

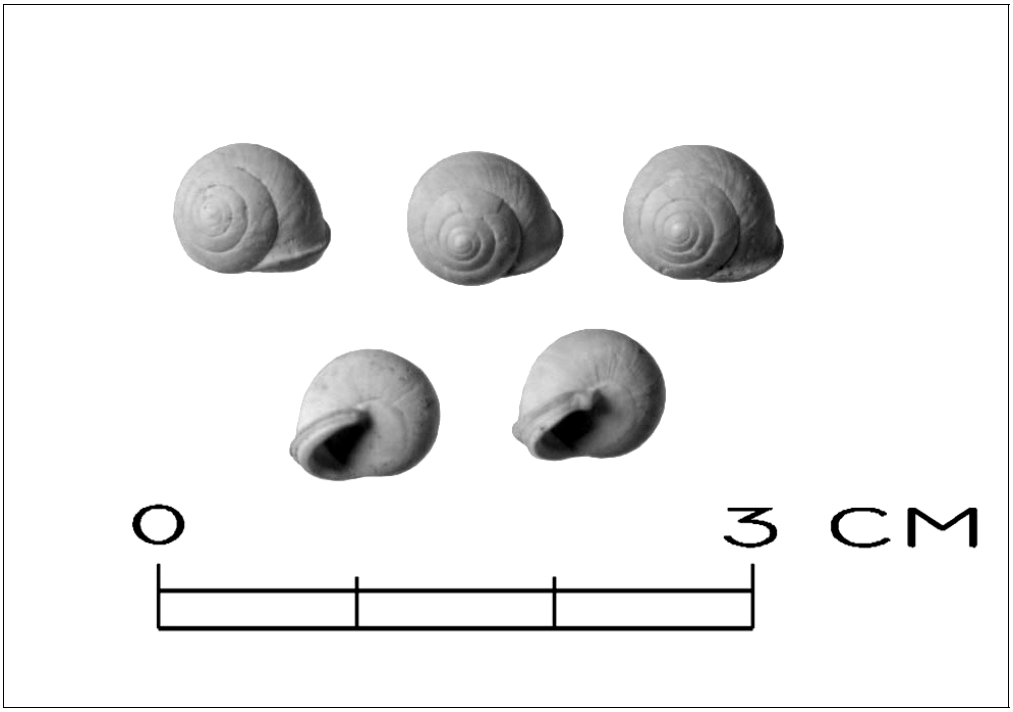


Figure 8.45. *Oligyra orbiculata.* Top row, apical view; bottom row, umbilical view. Five specimens out of 537 from N112 E97 (93.14-92.75 m), bag 1 of 2, Lot B-111.

Fullington and Pratt also claim that the species is absent from grassland, but I have seen it many times in South Texas grassland with only scattered shrubs or trees. Hubricht (1985:3) says "A calciphile. Prefers sunny situations, roadsides, and glades. It sometimes occurs in woods, but is not as abundant in such habitats." In Kaufman County, it occurs in "woodlands, exposed areas such as pastures and grass lands… on the trunks of *Celtis occidentalis* and the surfaces of logs in the woodlands of Forney (C); on leaf debris at the Terrell pasture (S); and on sticks…." (Logsdon 1967:78).

According to Cheatum (1934:147),

> *H. o. tropica* is one of the most abundant species of terrestrial gastropods occurring in Dallas County, Texas. After a light shower one can collect hundreds of individuals that are creeping over weeds and grasses in many pasture lands. Since it is a snail that is especially hardy and has a great resistance to drouth, individuals appear to be as abundant in exposed areas as in protected woodland regions.

This species often appears in large numbers in archeological sites. Almost 20,000 specimens were recovered from just a few units at the Rice's Crossing site (Brown and Hughes 2003), and almost 10,500 were recovered from the combined 1/4-inch and 1/8-inch mesh sample in a single 1 x 1 m unit at the Smith Creek Bridge site. The dominance of this species may be missed by conventional screening methods, though, because archeologists rarely collect this species, and many of the shells will pass through 1/4-inch mesh (at the Smith Creek Bridge site, this mesh captured only 53% of the *Oligyra*; Brown 2002:260). Juveniles and smaller adults will be missed. At the Wilson-Leonard site, when the entire stratigraphic section is considered (including Archaic midden deposits; Shaw *et al*. 1998:Table 37-2), over 31, 000 *Oligyra* were recovered using 1/4-inch and 1/16-inch mesh, and the species represents 70% of the medium and large-bodied snails recovered. At some sites, this species appears in very large numbers at the top of the stratigraphic section, declining greatly in frequency downward. Some examples include the Smith Creek Bridge site (Brown 2002:Fig. 97), Wilson-Leonard, and various sites in the Hog Creek Reservoir and Leona Watershed projects. I have discussed this trend in the Smith Creek Bridge site report (Brown 2002:263-264). This downward decline in frequency is not likely to be taphonomic in origin, because the shells of this species are exceptionally durable.

Although *Oligyra orbiculata* is a catholic, stress-resistant species capable of adapting to both wet and dry environments, paleoenvironmental evaluation requires assessment of the entire assemblage. At sites where this species appears in large numbers to the near-exclusion of other species, it is reasonable to assume the environment was xeric or otherwise stressful, and *Oligyra* was able to out-compete other snail species. Environmental stress could be regional and climatic in nature, or it could be a result of prehistoric occupants of a site clearing vegetation and packing the topsoil with foot traffic. In stratigraphic levels where *Oligyra* is among several species that simultaneously increase in number, interpretation becomes more complex, especially if the other species are mesic woodland indicators. In cases like that, changing depositional rates and admixture of species from different habitats might be implicated.

If *Oligyra* is a marker species for drought-prone Holocene climates, it might be worthwhile to inquire how common it is in Late Pleistocene sites that are situated within its present range in Texas. At the Aubrey site, the species is quite rare; none were found in the pond margin, and only one was found in the pond axis samples (Neck 2001:Tables 7.2, 7.3). At the Pavo Real site, about 21% of the snails from Zone 5 are *Oligyra* (Table A3-2 in Brown 2003 is incomplete because of an editing error); in Zone 6, about 36% are *Oligyra*, and in Zone 7, six out of eight snails are *Oligyra*. At the Richard Beene site, I estimate about 20% of the medium or large-bodied terrestrial snails from the Late Pleistocene-early Holocene levels are *Oligyra* (samples below the Elm Creek paleosol, based on Neck 1992:Table 4, and omitting microsnails). At the Wilson-Leonard site, the species represents about 51% of the medium and large-bodied snails in Unit I. Preservation is undoubtedly an issue at some of these other early sites. Particularly at the

Wilson-Leonard site, I suspect the species is disproportionately represented because more fragile genera like *Mesodon* have been taphonomically deleted from the lower deposits.

In the bench deposits at Berger Bluff, *Oligyra orbiculata* represents about 45% of the medium-bodied and large-bodied snails recovered from the 1/4-inch screen (microsnails are omitted from this estimate) from all levels and units. When this percentage is plotted vertically on a unit-by-unit basis, the stratigraphic patterns that emerge vary from unit to unit. In some units, such as N112 E97 and perhaps N109 E96, there is a clear trend for increasing dominance of the species over time. In other units, such as N109 E103, N110 E102, N111 E101, and N112 E99, the distribution is erratic in the lower levels (due to small sample sizes) and stable or only slightly increasing in the upper levels. Figure 8.46 shows the pattern for some of these units. There seems to be a weak trend for the species to become more dominant toward the top of the bench deposits, a trend that cannot be ascribed entirely to taphonomic processes. In Figure 8.26, it appears that the chief source is the reduction in the relative number of *Anguispira* in the upper part of the bench deposits. I suspect this indicates advancing desiccation of the habitat as the Holocene is entered.

In the bench deposits, this species is interpreted as a cosmopolitan, eurytopic, drought-resistant snail that can tolerate both wet and dry conditions, and is well-adapted to continental Holocene climates. It may indicate the presence of open xerithermic habitats.

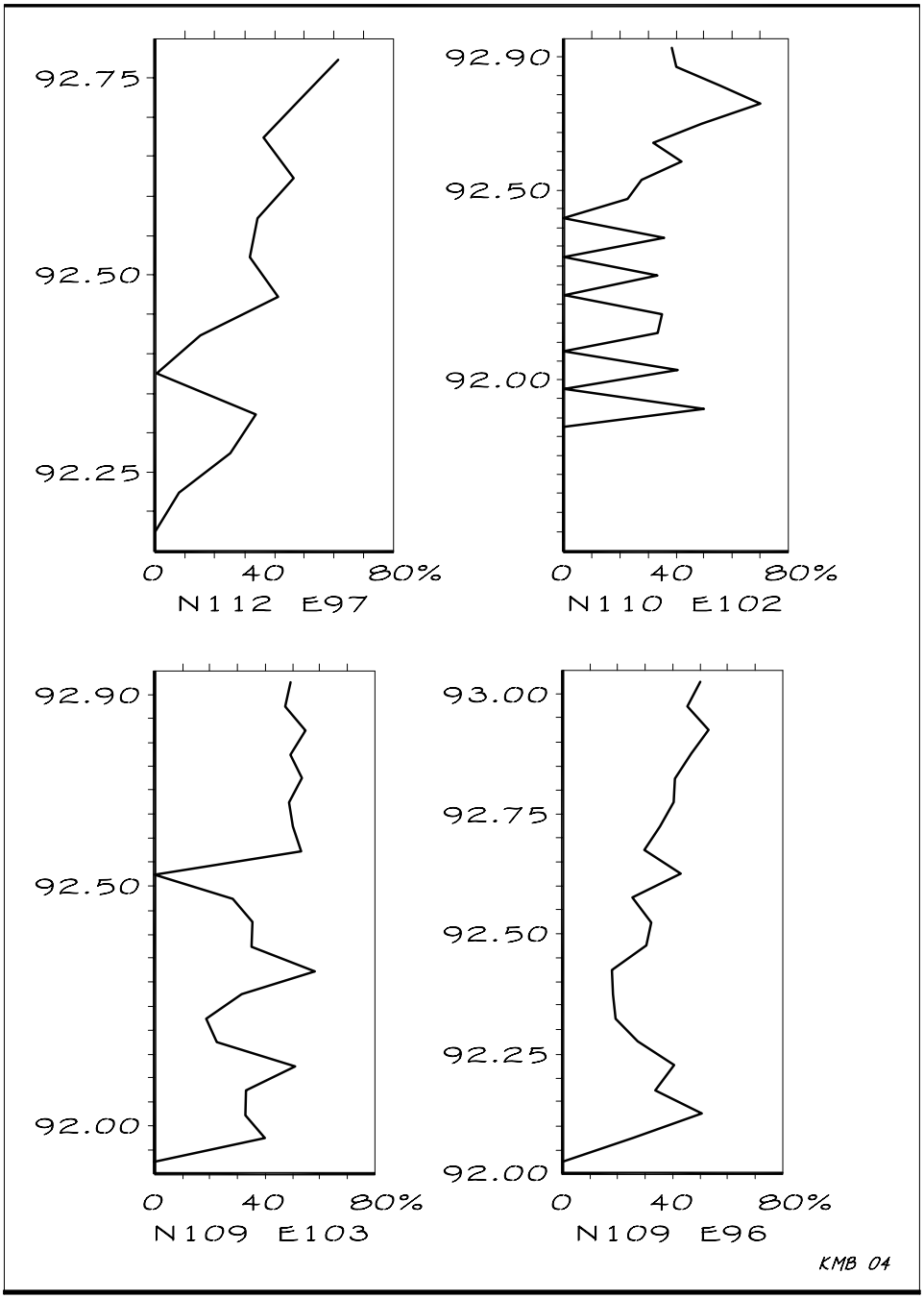


Figure 8.46. Vertical Distribution of *Oligyra orbiculata*. Frequency of *O. orbiculata* as a percentage of medium and large-bodied snails recovered from the ¼-inch screen is shown here for four units. Microsnails and data from matrix samples are omitted. Only the top two units show a slight indication of increase in the species near the top of the bench.

Polygyra (Millerelix) mooreana, PMOO

Matrix columns: 98 specimens
1/4-inch screen sample: none
Body size: Medium-bodied, diameter 6.5-8.5 mm (Cheatum and Fullington 1971:17), diameter 7.3 ± 0.4 mm (range, 6.7-8.3 mm; Pratt 1981:28)

In his 1982 analysis of two matrix columns, Raymond Neck identified 98 out of 108 *Polygyra* specimens as *Polygyra mooreana* (revised to *Millerelix mooreana* by Pratt 1981). Neck identified no *Polygyra texasiana* at all in the N109 E103 column, and only 10 specimens in the N110 E102 column. However, Neck's analysis did not consult Pratt's extensive revision and detailed study of Texas polygyrids, which had only recently become available. When I examined the *Polygyra* from the Smith Creek Bridge site (295 specimens), I found that essentially all specimens corresponded best to *Polygyra texasiana triodontoides*, a new subspecies endemic to De Witt County defined by Pratt (1981:70-72). This subspecies is intermediate in size between *P. mooreana* and *P. texasiana texasiana* and higher-domed than either (see Table 8.14).

Examination of specimens from the 1/4-inch screen sample of the bench deposits (851 specimens) shows that they, too, conform best to *Polygyra texasiana triodontoides*. Although I have not re-examined the *Polygyra* specimens in the matrix samples studied by Neck, I suspect they, too, are most likely. *P. texasiana triodontoides*.

Pending further study of the *Polygyra* from the matrix columns, I have retained Raymond Neck's classification as *P. mooreana* and *P. texasiana*. My expectation, however, is that probably all of the *Polygyra* at Berger Bluff are *Polygyra texasiana triodontoides*.

Regarding *Polygyra mooreana*, Cheatum and Fullington (1971:17) report "Occurs in a variety of habitats, ranging from deep moist woodlands to sparsely-timbered hillsides where rocks and debris afford protection and preserve moisture." Pratt (1981:31) says "*Millerelix mooreana* inhabits rocky slopes, generally in oak or oak-juniper woodland, and always on a calcareous substrate, either limestone, shale, or occasionally a calcareous cemented sandstone. It is absent from dry hilltops and seems to be replaced *by Polygyra texasiana* on valley floors and stream floodplains."

Polygyra texasiana triodontoides (Fig. 8.47), PTEX

Matrix columns: 10 specimens recorded as *P. texasiana*, but not the nominate subspecies
1/4-inch screen sample: 884 specimens (plus 231 fragmentary unidentified *Polygyra*)
Body size: Medium-bodied, diameter 8.3 ± 0.4 mm (range, 7.8-8.1 mm; Pratt 1981:70)

See the taxonomic discussion above. *Polygyra texasiana triodontoides* is a subspecies defined by Pratt (1981:70-72). All or nearly all of the *Polygyra* from the 1/4-inch screen seem to conform best to this subspecies, which is intermediate in size and shape between *Polygyra mooreana* and *Polygyra texasiana texasiana*. There are 884 whole specimens plus another 231 damaged specimens that are likely the same species, for a total of 1115. Table 8.14 shows how the shell dimensions compare to the biological definitions and to a large sample from the Smith Creek Bridge site. Figure 8.49 graphically portrays shell diameter and height for the bench specimens from the 1/4-inch screen.

In Figure 8.48, a very small number of outliers can be seen on both the left (about 5 specimens) and right (about 5 specimens) sides of the histograms. The outliers on the left could be scarce examples of *Polygyra mooreana*, and those on the right could be

Polygyra texasiana texasiana, or they might simply be aberrant *triodontoides* individuals. All of these species tend to intergrade and hybridize to some extent.

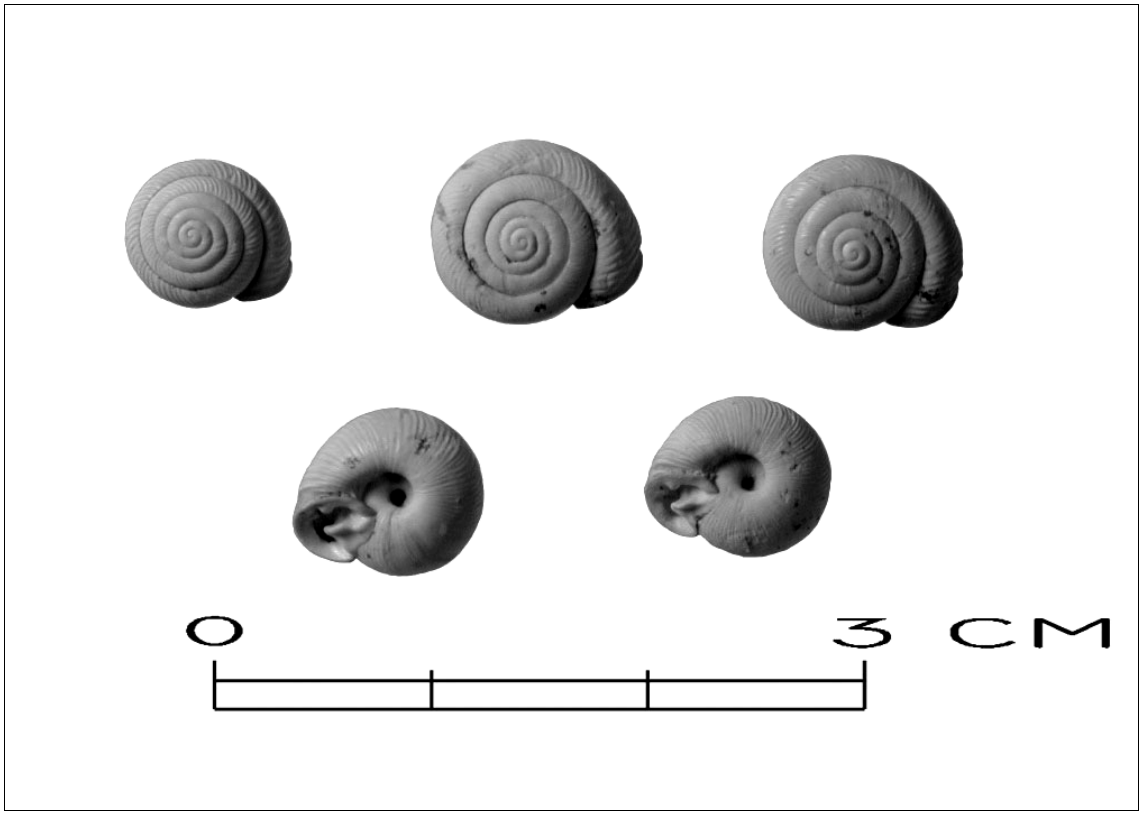


Figure 8.47. *Polygyra texasiana triodontoides*. Top row, apical view; bottom row, umbilical view. Selection of five specimens out of 100 from N112 E97 (93.14-92.75 m), bag 1 of 2, Lot B-111. Top left specimen resembles *P. mooreana* morphotype.

The *triodontoides* subspecies, as recognized by Pratt, has a much smaller geographic range than the *texasiana* subspecies. Its type locality is in De Witt County, and it extends into Louisiana in a narrow band along the coast (Fig. 8.49; compare with Fig. 8.16; see also Hubricht 1985:Map 375). According to Pratt (1981:72), "*Polygyra texasiana triodontoides* is a form of the Gulf Prairies and their included fresh-water marshes. It is characteristically found in wetter areas than *P. t. texasiana*." Hubricht

(1985:38, as *Polygyra triodontoides*) says "found in the litter in low, wet ground near ponds and lakes and along rivers." Regarding the *texasiana* subspecies, Cheatum and Fullington (1971:12) say that it "occupies a variety of habitats ranging from deep woodlands to open prairies, where it may be found under rocks and other objects. During drouth, well-formed epiphragms may be present that seal the aperture, thus preventing water loss."

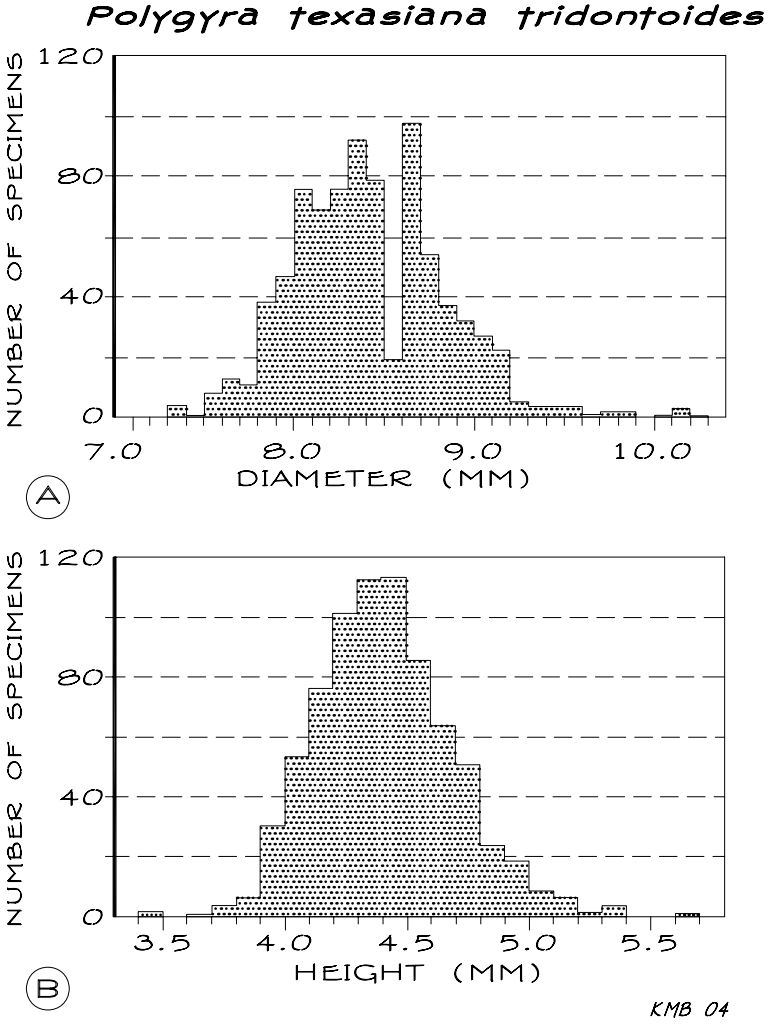


Figure 8.48. Histograms of *Polygyra texasiana triodontoides* Body Size. A, diameter (N = 830); B, height (N = 756) for specimens from ¼-inch screen, all units except Unit 2 and N113 E98.

Table 8.14. Metric Statistics for *Polygyra* Species.

Contemporary biological samples

Millerelix (Polygyra) mooreana (Pratt 1981:28)

mean diameter	7.3 ± 0.4 mm (range, 6.7-8.3 mm)
mean height/diameter ratio	0.52 ± 0.02 mm (range, 0.49-0.55)

Polygyra texasiana triodontoides (Pratt 1981:70)

mean diameter	8.3 ± 0.4 mm (range, 7.8-8.1 mm)
mean height/diameter ratio	0.56 ± 0.03 (range, 0.50-0.61)

Polygyra texasiana texasiana (Pratt 1981:61)

mean diameter	9.5 ± 0.7 mm (range 8.8-10.7 mm)
mean height/diameter ratio	0.49 ± 0.02 (range 0.45-0.53)

Archeological samples

Polygyra texasiana triodontoides (Brown 2002:Table 71)
Smith Creek Bridge site, N51 E101, all levels, 1/4-inch and 1/8-inch mesh

mean diameter	8.86 ± 0.75 mm (range, 6.8-11.0 mm, N = 295)
mean height/diameter ratio:	not recorded

Polygyra texasiana triodontoides
Berger Bluff bench, all units except Unit 2 and N113 E98, 1/4-inch screen sample

mean diameter	8.34 ± 0.40 mm (range, 7.3-10.2 mm, N = 830)
median diameter	8.30 mm
mean height	4.45 ± 0.28 mm (range, 3.50-5.62 mm, N = 756)
median height	4.40 mm
mean height/diameter ratio	0.5328 ± 0.0400 (range, 0.4382-0.6347, N = 735)
median height/diameter ratio	0.5341

Figure 8.49. Approximate Range of *Polygyra texasiana triodontoides* in Texas as Mapped by Pratt. Map adapted and generalized from Pratt (1981:Fig. 13). Compare with Fig. 8.16.

In the bench deposits, this species is regarded as an indicator of mesic floodplain habitats, probably with deciduous tree cover. Specimens are largely restricted to the upper part of the bench deposits, probably because of shell destruction in the lower strata.

Praticolella cf. *P. pachyloma* (Fig. 8.50), PRAP

Matrix columns: 13 specimens identified as *P. berlandieriana* by Raymond Neck
1/4-inch screen sample: 30 specimens, plus 78 fragmentary (probably *P. pachyloma*)
Body size: Medium-bodied, diameter 8.5-11.0 mm, height 7.5-9.0 mm (Hubricht 1983:246)

In 1982, Raymond Neck originally identified all 13 *Praticolella* specimens found in the N109 E103 and N110 E102 matrix columns as *Praticolella berlandieriana*. However, Hubricht (1983) later published improved descriptions and illustrations of all *Praticolella* species in Texas, and based on his species definitions, I assigned all of the *Praticolella* specimens at the Smith Creek Bridge site to *Praticolella pachyloma*, a species that is closely related but higher-domed. The Smith Creek Bridge site is an instructive case, because after plotting all the specimens from the N51 E101 study column that were intact enough to measure (N =287), it became clear that there was far more variability in size than allowed for by the published biological species definitions (see Brown 2002:Fig. 101). This suggests the biological definitions are based on inadequate data. Figure 8.52 is a reproduction of the Smith Creek Bridge site data. Many of the Smith Creek Bridge site specimens are much larger than the published ranges for either species.

When the Berger Bluff bench specimens from the 1/4-inch screen sample are plotted the same way, the pattern is less clearcut, because there are far fewer (N = 24) intact, measurable specimens at Berger Bluff than at the Smith Creek Bridge site. Here, many of the specimens are smaller than provided for in the biological definitions (Figs. 8.53, 8.54). When all of the *Praticolella* metric data are considered (Table 8.15), it is apparent that small sample of Berger Bluff bench specimens is more or less metrically

intermediate between *P. pachyloma* and *P. berlandieriana*. This is not surprising, since these species readily hybridize and intergrade.

Figure 8.50. *Praticolella cf. P. pachyloma*, Adaxial View. Specimen from N109 E103 (92.70-9.65 m), Lot B-10.

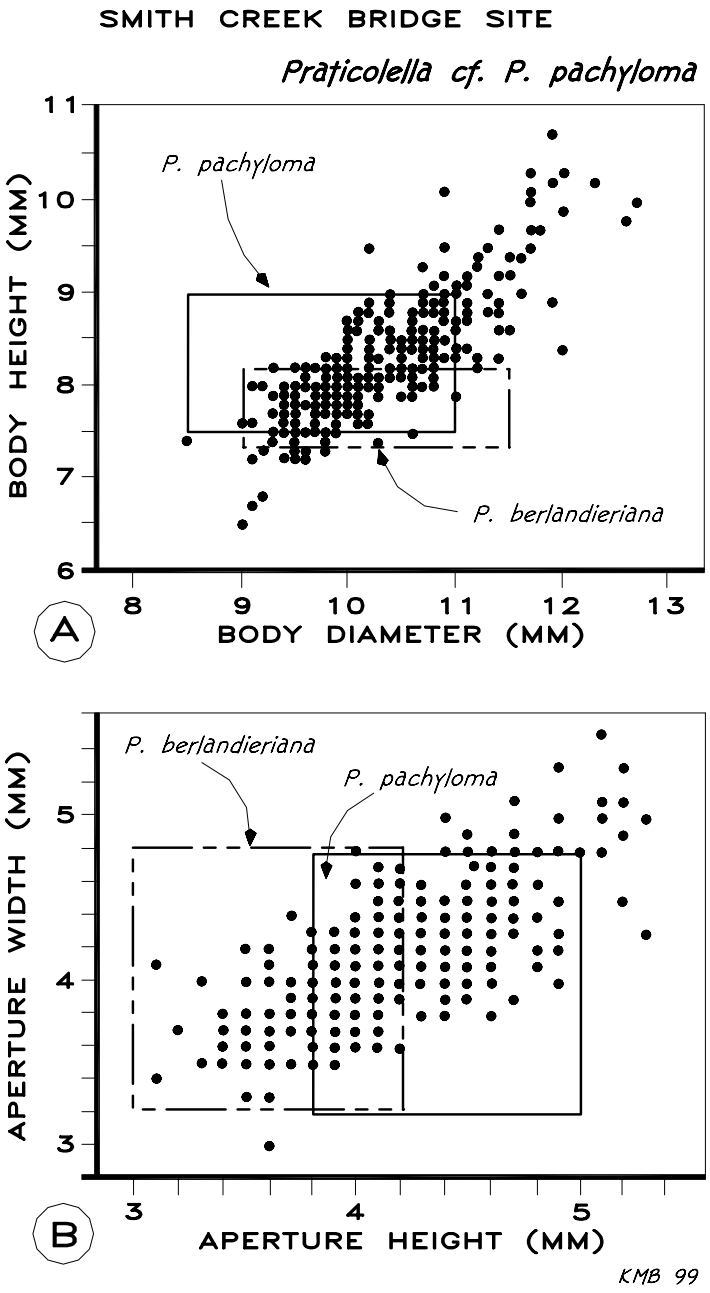


Figure 8.51. *Praticolella* Height vs. Diameter, Smith Creek Bridge Site. A, scatterplot of body height vs. diameter (N = 287) for all measurable specimens from N51 E101 at the Smith Creek Bridge Site. B, scatterplot of aperture height vs. width (N =409). Illustration after Brown (2002:Fig. 101).

When morphology rather than size is considered, the more complete specimens from the bench deposits appear to resemble *Praticolella pachyloma* more than *Praticolella berlandieriana*; in sorting, 26 specimens were classified as *P. pachyloma*, none were classified as *P. berlandieriana*, and the rest were indeterminate or too damaged for classification. In summary, the specimens from the bench seem best considered as *Praticolella pachyloma* or perhaps a hybrid between this species and *P. berlandieriana*. The bench specimens are high-domed, with an aperture that is almost equal in height and width. They are, however, smaller and less elevated than the Smith Creek Bridge site specimens. The height/diameter ratio for the bench specimens is 0.7946, which is almost exactly the same as for the illustration presented by Hubricht (1983:Fig. 4). It is possible that the bench specimens are more hybridized with *P. berlandieriana* than are those from the Smith Creek Bridge site.

Regarding geographic range (Fig. 8.14) and habitat preference, the following is quoted from the Smith Creek Bridge site report:

> The present distributions of two species of *Praticolella* overlap in the De Witt County area. According to Hubricht, *P. pachyloma* occupies the south, central, and much of the upper coastal plain, while *P. berlandieriana* occurs farther inland in central and east-central Texas (Hubricht 1983:Map 1, 1985:Maps 430, 432) and reportedly extends into Nuevo Leon and Tamaulipas (Correa Sandoval 1997:139). Cheatum and Fullington show the two distributions as more nearly coinciding (Cheatum and Fullington 1971:Fig. 11, 12). Neck has recognized both species co-occurring at archeological sites in Fort Bend County. At one site, *P. berlandieriana* predominates (Neck 1986b), while at the other (Neck 1991a), the proportions are reversed. According to Neck (1991a:16), *P. pachyloma* prefers sandy soils, while *P. berlandieriana* prefers clay or loamy soils, and "disturbed habitats, particularly those with wide expanses of bare soil" (Neck 1987b; see also Neck 1994a:150).
>
> It is perhaps significant that *P. pachyloma* seems to have the widest environmental tolerance of the various *Praticolella* species. Its inland counterpart, *Praticolella berlandieriana*, can be found in wooded floodplains, in brush thickets, or in grassland; in rainy weather it climbs bushes and in dry weather

burrows in topsoil or under downed wood (Pilsbry 1940:695). *Praticolella pachyloma* is found in either open or wooded habitats, usually in sandy soil or under litter (Hubricht 1985:41-42). Branson (1960:151) reports it from floodplain and brushy habitats in San Patricio County (Brown 2002:222-223).

Praticolella specimens from the bench deposits are regarded as most likely *Praticolella pachyloma* or a closely related hybrid, probably derived from a well-drained sandy habitat. Specimens are most common in the upper part of the bench deposits, but are also found in the lower strata, including one example found in the upper part of stratum 1. These snails are large enough for adults to be captured by the 1/4-inch screen, but are often incomplete due to collapsed spires.

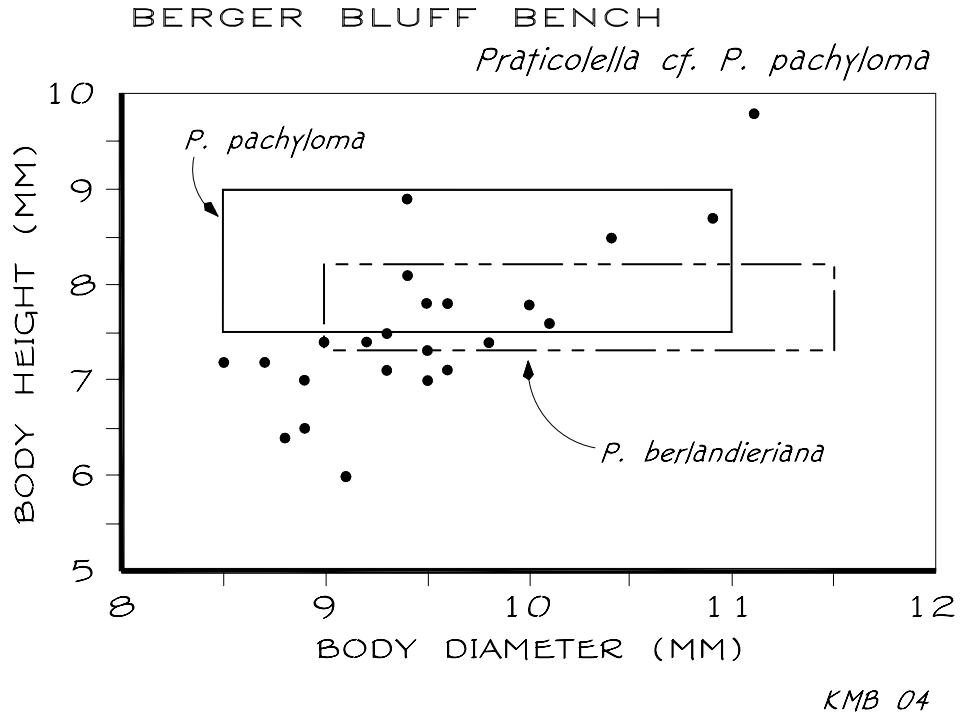


Figure 8.52. *Praticolella* Height vs. Diameter, Berger Bluff Bench. Scatterplot of body dimensions for all measurable specimens from the ¼-inch screen (N = 24).

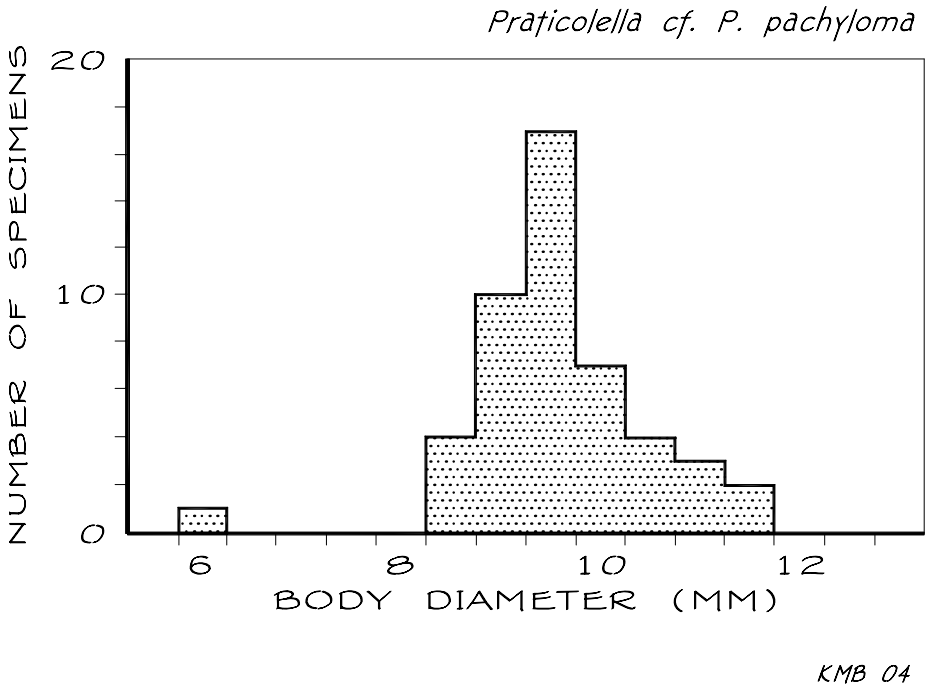


Figure 8.53. Histogram of Body Diameter, *Praticolella* cf. *P. pachyloma*. All specimens measurable for diameter (N = 48) are shown for the ¼-inch screen sample from the bench deposits.

Table 8.15. Metric Statistics for *Praticolella* Species.

Contemporary biological samples

Praticolella berlandieriana (Hubricht 1983:246)

diameter	9.0-11.5 mm
height	7.3-8.2 mm
aperture height	3.2-4.1 mm
aperture width	3.0-4.2 mm

Praticolella pachyloma (Hubricht 1983:246)

diameter	8.5-11.0 mm
height	7.5-9.0 mm
aperture height	3.8-5.0 mm
aperture width	3.2-4.8 mm

Archeological samples

Praticolella pachyloma (Brown 2002:Table 72)
Smith Creek Bridge site, N51 E101, all levels, 1/4-inch and 1/8-inch mesh

mean diameter	10.33 ± 0.77 mm (range, 6.8-11.0 mm, N = 370)
mean height	8.32 ± 0.67 mm (range, 6.5-10.7 mm, N = 290)
mean H/D ratio	0.8033 ± 0.0382 (range, 0.7000-0.9314, N = 284)
mean aperture height	4.18 ± 0.40 mm (range, 3.1-5.3 mm, N = 410)
mean aperture width	4.16 ± 0.37 (range, 3.0-5.5 mm, N = 409)
whorls	5.20 ± 0.21 (N – 278)

Praticolella pachyloma
Berger Bluff bench, all units except Unit 2 and N113 E98, 1/4-inch screen sample

mean diameter	9.40 ± 0.87 mm (range, 6.00-11.10, N =48)
mean height	7.54 ± 0.83 mm (range, 6.00-9.80, N = 24)
mean H/D ratio	0.7946 ± 0.0594 (range, 0.6593-0.9468, N = 24)
mean aperture height	3.65 ± 0.30 mm (range, 3.10-4.40, N =50)
mean aperture width	3.78 ± 0.37 mm (range, 2.70-4.70, N = 53)
whorls	not recorded
median diameter	9.35 mm
median height	7.40 mm
median aperture height	3.60 mm
median aperture width	3.70 mm

Pupisoma dioscoricola (Fig. 8.54), PUPD

Matrix columns: 9 specimens
1/4-inch screen sample: 1 specimen
Body size: Microsnail, diameter 1.5-1.8 mm, height 1.5-2.0 mm (Cheatum and Fullington 1973:26)

This is one of the smallest microsnails found in the bench deposits, and one of the most informative. It is a coastal plain species with a discontinuous range extending from Texas through Louisiana, Mississippi, Alabama, Georgia, South Carolina, and much of Florida (Hubricht 1985:Map 98). Hubricht terms is a "widely distributed Neotropical species." It also occurs in Mexico (in gallery woodland; Correa Sandoval 1997:Table 1, 2003) and South America; the type locality is in Jamaica (Pilsbry 1948:1008). In Texas, it is recorded by Cheatum and Fullington (1973:26) in the counties of Cameron, Hidalgo, Live Oak, Liberty, Brazos and Gonzales. McGee (1965:131) reports it from several more counties, including Brazoria, Cameron, Harris, Hidalgo, Fayette, Lavaca, Matagorda, San Patricio, and Victoria. It is "an arboreal species. Most frequently found on the undersides of palmetto leaves… The slime of species of this genus is much more adhesive than that of other land snails. They are not as likely to be dislodged by storms as other arboreal species would be" (Hubricht 1985:12). Cheatum and Fullington (1973:27) report "we have collected *P. dioscoricola* on the underneath surface of palmetto leaves and have found it in nearly all palmetto growths in which we have collected in south Texas. Although never abundant, it has been present. Hubricht (Correspondence, November 22, 1971) informs us that it also occurs on the trunks of ironwood during wet weather." I have repeatedly checked the undersides of palmetto leaves in Travis County for this species myself and have never seen it, so evidently central Texas is too dry to support it.

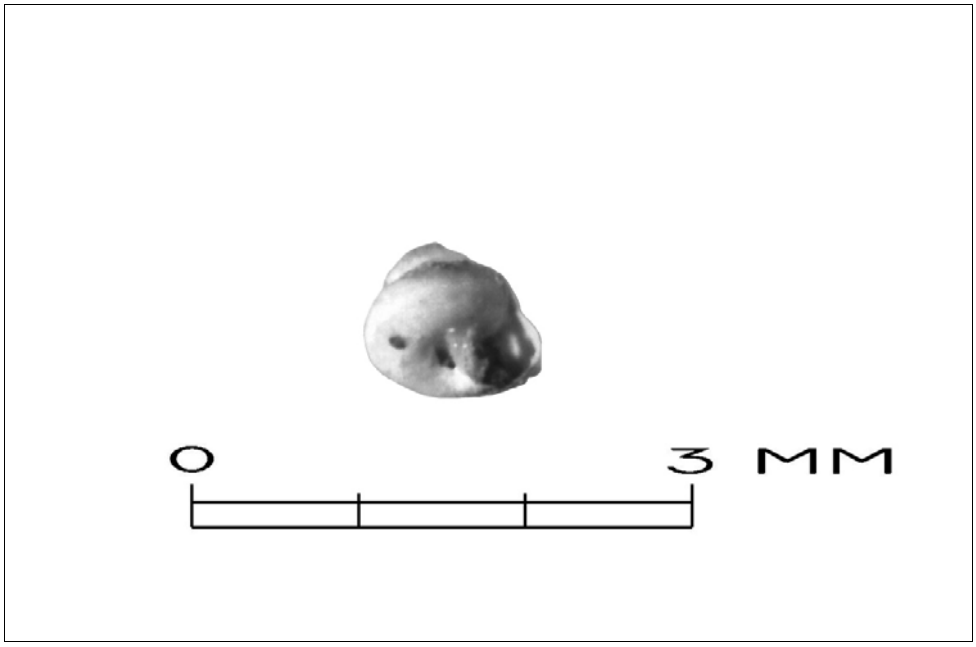


Figure 8.54. *Pupisoma dioscoricola* (?). Oblique basal view of damaged specimen tentatively identified as *Pupisoma dioscoricola*, from N109 E103 (92.80-92.75 m), Lot B-7, fortuitously recovered from ¼-inch screen sample.

Because this species is very small and resembles an embryonic polygyrid, it can easily be overlooked or misclassified. I am aware of no other archeological reports in Texas or nearby states, and the only paleontological locality I can find is the Wood Pit channel deposit (Slaughter *et al*. 1962:49) in north Texas. In the bench deposits, this species is taken as a good indicator of mesic floodplain habitat, probably supporting native palmetto. Dwarf palmetto (*Sabal minor*) is still present on the Coleto Creek terraces today (Espey, Huston and Associates 1976:Table 2-18). Although only nine specimens are present in the matrix columns, they have an interesting distribution. Eight of the nine occur below 92.45 m, and only one was found in the upper part of the bench deposits. A single probable specimen (diameter, 1.0 mm) was fortuitously recovered from the 1/4-inch screen in unit N109 E103 (92.80-92.75 m).

Pupoides albilabris (Fig. 8.55), PALB

Matrix columns: 31 specimens
1/4-inch screen sample: 3 specimens
Body size: Microsnail, height 4.2-5.0 mm (Cheatum and Fullington 1973:28); 4.2-4.9 mm (Logsdon 1967:54); 4.5-5.6 mm (Leonard and Goble 1952:1035)

This small, arid-tolerant, conical snail is widespread in Texas and occurs rather commonly in contemporary biological surveys, archeological and paleontological sites. It is larger and somewhat more durable than many of the other microsnails, and according to Bequaert and Miller (1973:79) is morphologically variable. A few specimens were found in the Preiss Ranch drift sample (Table 8.8), but not in either of the excavated quadrats. It occurs throughout the eastern US (Hubricht 1985:Map38) and westward as far as the Dakotas, Colorado, Utah (Oliver and Bosworth 1999:Fig. 51), New Mexico (Metcalf and Smartt 1997:27), and Arizona, as well as northern Mexico (including Baja California) and the Caribbean. It was the single most commonly encountered species in the Southern Plains Gastropod Survey (Wyckoff, Theler and Carter 1997:32; see also Branson 1961a:52), occurring in low numbers but high ubiquity on all landform types. According to Cheatum and Fullington (1973:28) it is "most abundant in limestone areas where it may be found under rocks, in grass root and under leaf litter in sparse woodlands." In Kaufman County, "this species was abundant in the grassy woodlands of the Reese Farm and was scarce in the Trinity bottom at Forney. It was taken from forest debris at Elmo (C); leaf litter at Talty (C); rich humus at Terrell (C); and grass debris in the pasture at the Linehan Farm (C)" (Logsdon 1967:53). In Kansas, Leonard and Goble (1952:1035) report "it was abundant in the steep, well-drained areas of the west-facing, wooded slope (SF). The species was common on limestone ledges at the summit of the north-facing slope and a few specimens were collected from the loose soil around the roots of tall grass and weeds." Metcalf (1984:60) says "*Pupoides albilabris* resembles

Gastrocopta pellucida in being tolerant of xeric conditions in the southwestern states. It was found in many localities and in various kinds of habitats." In New Mexico, "*Pupoides albilabris* may be found in brushy areas under stones or in leaf litter. In the southern part of the state, it may occur under stems of dead yuccas and dead, detached caudices of sotol" (Metcalf and Smartt 1997:27).

Figure 8.55. *Pupoides albilabris,* Adaxial View. N109 E103 (93.14-92.90 m), Lot B-1.

As might be expected, this species occurs rather commonly in archeological and paleontological sites and can be readily retrieved in fine-mesh samples. Archeological finds include Aubrey, Lubbock Lake, Lake Theo, Rex Rodgers, Sulphur Springs (Neck 1994 d), Denton Creek, Wilson-Leonard, Richard Beene, Mustang Branch, Winston's Cave, Anthon, Buckhollow, Gaulding, Guadalupe Bay, 41 CC 112, 41 FB 32 (Neck 1991a), 41 WM 118, 41 WM 130, 41 WM 312, 41 TV 368, 41 CH 56, 41 MK 38 (Todd 2002), and the Burnham site. It was not found at the Domebo or Hajny Mammoth sites, despite the fact that it is a common Oklahoma species. References for all these sites can be found in the preceding species accounts. It was recovered in large numbers from the historic component of 22 OK 904 in Mississippi (Peacock and Melsheimer 2003:Table 3.1); here it seems to occupy a dry microhabitat in an otherwise humid region.

In the bench deposits, this species is regarded as a eurytopic snail capable of tolerating either damp or very dry conditions ranging from the aridity of northern Mexico to the humidity of Florida. Likewise, its temperature tolerance extends from Maine to Florida and the Gulf coast. It can also tolerate the extremes of continental climate found on the Plains in Oklahoma, Kansas and South Dakota. The relatively small number of specimens from the bench deposits is scattered throughout the stratigraphic sections, and there is one specimen from the upper part of stratum 1. If this species can be taken as a continental climate indicator, its relatively low numbers probably indicate that local climate was not strongly continental in the Younger Dryas and early Holocene.

Rabdotus cf. *R. dealbatus* (Fig. 8.56), RAB

Matrix columns: 158 specimens
1/4-inch screen sample: 1127 specimens (462 adults, 535 juveniles, 130 indeterminate)
Body size: Large-bodied, height 17.0-33.0 mm (Fullington and Pratt 1974:16), 14.7-26.2 mm (Logsdon 1967:69), 16.3-26.0 (Burch 1962:133)

The species of *Rabdotus* present in the bench deposits is something of an enigma. According to Fullington and Pratt (1974) and Hubricht (1985), the geographic ranges of three species (*Rabdotus dealbatus, R. mooreanus*, and *R. alternatus*) overlap in Goliad County, but all of the recently dead *Rabdotus* visible on the surface in the catchment area appear to be very small, thin-walled *Rabdotus dealbatus* (Table 8.16), distinguished mainly by gray-brown stripes on the shell surface.

These three species are only weakly differentiated. They overlap greatly in size and shape, and because of bleaching and loss of pigmentation, archeological examples are difficult to speciate. Problems of identification are addressed at length in the Smith Creek Bridge site report, and the reader is referred there (Brown 2002:229-238) for a more much thorough discussion. *Rabdotus alternatus alternatus* is the largest species (Table 8.16). It is robust and thick-walled, relatively slender in shape, and is sometimes characterized by a slight swelling on the columella, by a thickened lip, and by reddish-brown pigmentation inside the aperture (Fullington and Pratt 1974:15). About 45% of the *Rabdotus* from the Smith Creek Bridge site had thickened lips and about 16% had reddish interiors. Most of the Smith Creek specimens seemed to correspond best to this species, so they were assigned to *Rabdotus alternatus* (Brown 2002:234-237), whose range extends from Mexico northward across the Rio Grande Plain (Fig. 8.17) to Berger Bluff. This is a colonial species characteristic of chaparral habitat in the lower Rio Grande valley (Pilsbry 1946:Fig. 2). According to Neck (1990c:2-3) "*R. alternatus* was most

abundant (18.6/m^2) where tall mesquite and cedar elm were dominant; snails were observed up to 11 m above soil level…. Optimum habitat of *R. alternatus* in this area occurs in the thorn woodland in an upland, well-drained environment." *Rabdotus mooreanus* is intermediate in size, but has about the same diameter/height ratio as *R. alternatus* (Table 8.16) and is characterized by a white, unpigmented shell. It is most often an open grassland or prairie species, but may also be found in gallery woodland (Fullington and Pratt 1974:18). Its range extends from the central coastal bend northwestward through central, Lower Pecos, and north-central Texas (Fullington and Pratt 1974:Fig. 7), where it is broadly sympatric with *R. dealbatus*, the latter usually occurring in woodland areas.

Rabdotus dealbatus is the smallest and most gracile of the three species, is relatively more obese, and recent shells are characterized by exterior gray-brown streaks. The interior is unpigmented and the lip may be somewhat thickened, but not as frequently or as heavily as in *R. alternatus*. It is also colonial and occurs widely through the eastern half of the state, except in the woodlands of deep east Texas (Fig. 8.18). It is the most mesic-adapted of the three species and ranges as far north as Kansas (Leonard 1959:103-104), where it is judged a recent invader, and as far east as Illinois, Kentucky, Tennessee and Alabama (Pilsbry 1946:8). It also extends westward into southern New Mexico (Hubricht 1985:Map 355). Except for isolated outliers, it is limited on the west in Texas roughly by the 22-32 inch (56-81 cm) isohyets (due to continentality effects, it tolerates drier conditions at the southern border of Texas than at the northern border). According to Fullington and Pratt (1974:16), it is "found under rocks, logs, and similar cover, emerging at night and during wet, overcast weather. During dry weather it is found cemented to the underside of cover objects or, rarely, to sheltered tree trunks or rock

ledges. It burrows several inches into the soil prior to winter hibernation…. In Texas it is generally found along stream bottoms and in similar open woodlands within the prairie, being replaced by *R. mooreanus* in open grasslands." Logsdon (1967:69) found these estivating on fence posts, on dead weeds in an open field, and under leaf litter in Kaufman County. Simmons reported

> It is found on the Leon River flood plain, up the steep hillsides, in the limestone bluffs, and over the hills into the treeless pastures where it is more abundant and most at home. It is found in populous colonies in the high open pasture lands where there is only grass and weed coverage.
>
> It can survive the severest drouths....This snail is often found by the hundreds where it has climbed weeds up 6 inches to 3 feet above the soil. It is notable that it always climbs dead, last years weeds....
>
> Here, in Coryell County in the limestone lands it attains greater size than in clay or sandy soils. To illustrate: a collection made in an abandoned field 6 miles to the southwest, the average height is 19 mm, whereas in a collection made on the high prairie lands approximately 250 feet above the river flood plain the average *B. dealbatus* is...height 26 to 28 mm., aperture 12 to 14 mm. high, 10 mm. wide (Simmons 1954:20-21).

Rabdotus shells from the bench deposits lack pigment, inside and out, and are a pinkish off-white in color. No systematic observations on columellar swellings or thickened lips were made, but in general, reinforced lips are occasionally present, but not nearly as well developed as in many of the Smith Creek Bridge site specimens. The mean diameter/height ratio for adults is 0.5639 (Table 8.17), which is consistent with either *R. mooreanus* or *R. alternatus*, but not *R. dealbatus*. The mean height for adults is about 26 mm, which is within the range of variation prescribed by Fullington and Pratt for any of

the three species. It is also considerably larger than any of the recently dead *Rabdotus* that can be collected in the region. Mean heights for recent *Rabdotus dealbatus* shells range from about 17-21 mm (Table 8.16). Mean heights for archeological specimens from south Texas range from about 23-28 mm (Table 8.17). Figure 8.57 shows shell heights and diameters for all adults from the 1/4-inch screen. Figure 8.58 shows the very same adult specimens combined with those juveniles that were retained on the screen (many embryonic specimens probably fell through or were destroyed, and are not shown here). Of the 997 *Rabdotus* specimens complete enough for age classification, 54% were juvenile and 46% were adult. This is a typical mortality profile for a contemporary death assemblage, and it is also typical for excavated assemblages from the 1/4-inch screen, provided the assemblage is not altered by human collecting bias (either prehistoric or archeological).

The *Rabdotus* adults from the bench deposits are actually slightly larger than the specimens tentatively assigned to *Rabdotus alternatus* from the Smith Creek Bridge site, yet they lack the pigmentation, columellar swelling, and frequent heavily reinforced lips found at that site. Are the specimens from Berger Bluff simply examples of *Rabdotus dealbatus* that are larger than most contemporary individuals? Or are they small examples of *Rabdotus alternatus* that lack some of the characteristic nominal attributes of the species? Among the collections from the 1/4-inch screen, there are five large specimens that compare well in size and shape with the presumed *Rabdotus alternatus* from the Smith Creek Bridge site. These are from N112 E 99 (92.89-92.60 m, Lot B-89, 2 specimens) and N112 E97 (93.14-92.75 m, Lot B-112, 1 specimen; 92.75-92.70 m, Lot B-113, 2 specimens).

Table 8.16. Metric Statistics for Contemporary *Rabdotus*.

Species definitions (Fullington and Pratt 1974)

Rabdotus dealbatus dealbatus	height 17-33 mm	D/H ratio	.57-.65
Rabdotus mooreanus	height 20-30 mm	D/H ratio	.47-.62
Rabdotus alternatus	height 23-43 mm	D/H ratio	.48-.63

Measured contemporary biological samples

Blue Bayou site, pooled samples 1 and 2 (Victoria County)
Rabdotus dealbatus adults (Brown 2002:Table 75)

mean height	17.55 ± 1.28 mm (range, 15.0-20.8, N =42)
mean diameter	10.82 ± 0.81 mm (range, 9.6-12.4, N = 44)
mean aperture height	8.88 ± 0.79 mm (range, 7.2-10.5, N =44)
mean aperture width	5.28 ± 0.50 mm (range, 4.3-6.8, N = 44)
mean diameter/height ratio	0.6189 ± 0.03 (range, 0.54-0.68, N = 42)

Diatom locality D-6 (Smith Creek, De Witt County)
Rabdotus dealbatus adults (Brown 2002:Table 75)

mean height	20.68 ± 1.41 mm (range, 18.8-23.4, N =10)
mean diameter	12.47 ± 0.82 mm (10.8-13.4, N = 10)
mean aperture height	10.72 ± 0.63 mm (9.6-11.5, N = 10)
mean aperture width	6.61 ± 0.42 mm (range, 5.8-7.2, N = 10)
mean diameter/height ratio	0.6037 ± 0.03 mm (range, 0.56-0.65, N = 10)

Welder Wildlife Refuge (San Patricio County)
Rabdotus dealbatus adults (samples courtesy of Andy Malof, 2001)

Patch 1	
mean height	19.30 ± 1.96 mm (range, 16.10-24.00, N =38)
mean diameter	11.64 ± 0.95 mm (range, 9.70-13.90, N = 40)
mean aperture height	10.03 ± 0.99 mm (range, 8.30-12.40, N = 40)
mean aperture width	6.38 ± 0.64 mm (range, 5.30-8.50, N = 40)
mean diameter/height ratio	0.6043 ± 0.0320 (range, 0.5450-0.6630, N =38)
Patch 2	
mean height	20.29 ± 1.68 mm (range, 15.90-25.40, N = 185)
mean diameter	11.91 ± 0.88 mm (range, 9.60-14.20, N = 187)
mean aperture height	10.42 ± 0.83 mm (range, 8.10-12.60, N = 188)
mean aperture width	6.65 ± 3.86 mm (range, 4.50-5.88, N = 188)
mean diameter/height ratio	0.5825 ± 0.0232 (range, 0.5276-0.6429, N = 183)
Patch 3	
mean height	19.13 ± 1.80 mm (range, 15.20-22.20, N = 16)
mean diameter	11.14 ± 0.95 mm (range, 9.20-13.00, N = 16)
mean aperture height	9.81 ± 0.98 mm (range, 7.40-11.80, N = 16)
mean aperture width	5.99 ± 0.69 mm (range, 4.70-7.10, N = 16)
mean diameter/height ratio	0.5830 ± 0.0211 (range, 0.5538-0.6230, N = 16)

Table 8.17. Metric Statistics for Archeological *Rabdotus*.

Camber site (Atascosa County; Turpin 2004:Appendix IV), *Rabdotus* sp.

mean height	25.88 ± 4.23 mm (range, 9-35, N = 634)

Blue Bayou site (Victoria County)
41 VT 94, Test Pit 21 (S0 W2.5, no levels), *Rabdotus* sp. adults

mean height	28.26 ± 2.11 mm (range, 23.04-32.8, N = 55)
mean diameter	16.52 ± 1.30 mm (range, 13.96-19.44, N = 62)
mean aperture height	15.07 ± 1.20 mm (range, 12.74-18.16, N = 66)
mean aperture width	not measured
mean diameter/height ratio	0.5894 ± 0.0291 (range, 0.5222-0.6630, N = 51)

Smith Creek Bridge site (De Witt County; Brown 2002:234)
N51 E101, all levels, *Rabdotus* cf. *R. alternatus* adults

mean height	24.83 ± 2.32 mm (range, 15.3-32.5, N = 3990)
mean diameter	14.56 ± 1.29 mm (range, 10.5-19.3, N = 4111)
mean aperture height	12.26 ± 1.15 mm (range, 7.6-16.8, N = 1936)
mean aperture width	7.40 ± 0.69 mm (range, 5.1-10.0, N = 1946)
mean diameter/height ratio	0.5874 ± 0.0286 (range, 0.4984-0.7202, N = 3934)

Berger Bluff, upper deposits
N97 E96, level 16 (97.70-97. 55 m), 1/8-inch screen sample, *Rabdotus* sp. adults

mean height	22.6 ± 2.96 mm (range, 16.28-27.34, N = 11)
mean diameter	12.36 ± 1.32 mm (range, 9.52-15.02, N = 11)
mean aperture height	11.94 ± 1.20 mm (range, 9.28-13.48, N = 11)
mean aperture width	not measured
diameter/height ratio	0.5712 ± 0.0332 (range, 0.5053-0.5937, N = 11)

Berger Bluff bench, 1/4-inch screen sample
All units pooled except Unit 2 and N113 E98, *Rabdotus* cf. *R. dealbatus* (?) adults

mean height	26.24 ± 2.78 mm (range, 18.90-32.70, N =72)
mean diameter	14.73 ± 1.47 mm (range, 11.40-19.20, N = 199)
mean aperture height	13.19 ± 1.50 mm (range, 8.28-17.70, N = 194)
mean aperture width	7.84 ± 0.97 mm (range, 5.50-11.20, N 155)
mean diameter/height ratio	0.5639 ± 0.0313 (range, 0.4841-0.6184, N =67)

median height	26.15 mm
median diameter	14.56 mm
median aperture height	13.12 mm
median aperture width	7.70 mm
median diameter/height ratio	0.5627

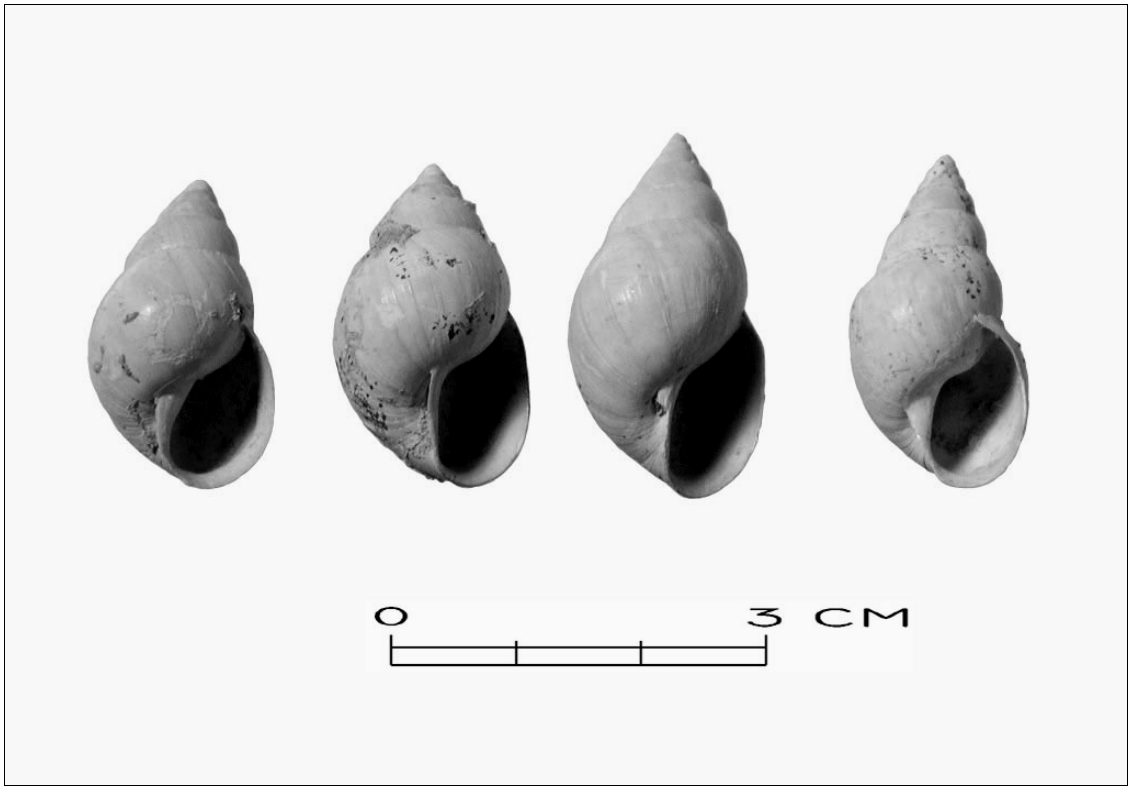


Figure 8.56. *Rabdotus* sp. Adults, Adaxial View. Four representative specimens from N112 E97 (93.14-92.75 m), Lot B-112.

Evaluating the 158 specimens from the two matrix columns, Raymond Neck initially considered many of them to be intermediate between *Rabdotus dealbatus* and *Rabdotus mooreanus*, but eventually classified them all as *Rabdotus dealbatus*. He also specifically commented,

> One species not found in the samples from Berger Bluff is the South Texas tree snail, *Rabdotus alternatus*. This species is found over most of southern Texas to the south and west of Berger Bluff. *R. alternatus* is not to be expected in the immediate vicinity of Berger Bluff, and its absence from the samples is not significant in regards to environmental reconstruction (Neck n.d.a:4).

I have followed Neck in tentatively classifying all of the *Rabdotus* from the bench deposits as *Rabdotus dealbatus*, but the classification is not quite so clearcut as portrayed by him. The specimens from the bench do not, in fact, correspond to modern *Rabdotus dealbatus* in pigmentation, shape factor, or size. Nevertheless, the overall match in terms of size, shape, and nominal attributes (such as lack of interior reddening, columellar swelling, and weak lip reinforcement) is perhaps better for this species than for the other two alternatives. The fact that archeological adult *Rabdotus* in south Texas are, on average, about 30% larger than contemporary specimens (when comparing collections that are not size-biased) needs explanation. The problems discussed above are a good example of the ambiguities that inhere in comparing archeological and modern faunas of any kind, when only hard parts can be observed archeologically, and when taphonomic biases or secular size changes may have altered the picture as well.

The *Rabdotus* specimens from the bench deposits are tentatively regarded as most likely a natural death assemblage of calciphile *Rabdotus dealbatus*, probably characteristic of either fairly well-drained, open woodland or of grassland. Although there is clear evidence of human occupation in the bench deposits, there is no indication any of the *Rabdotus* were used as food sources this early in the history of the site. The large assemblages of *Rabdotus* in the blufftop stratum 5 midden and at the Smith Creek Bridge site, on the other hand, were probably largely food remains.

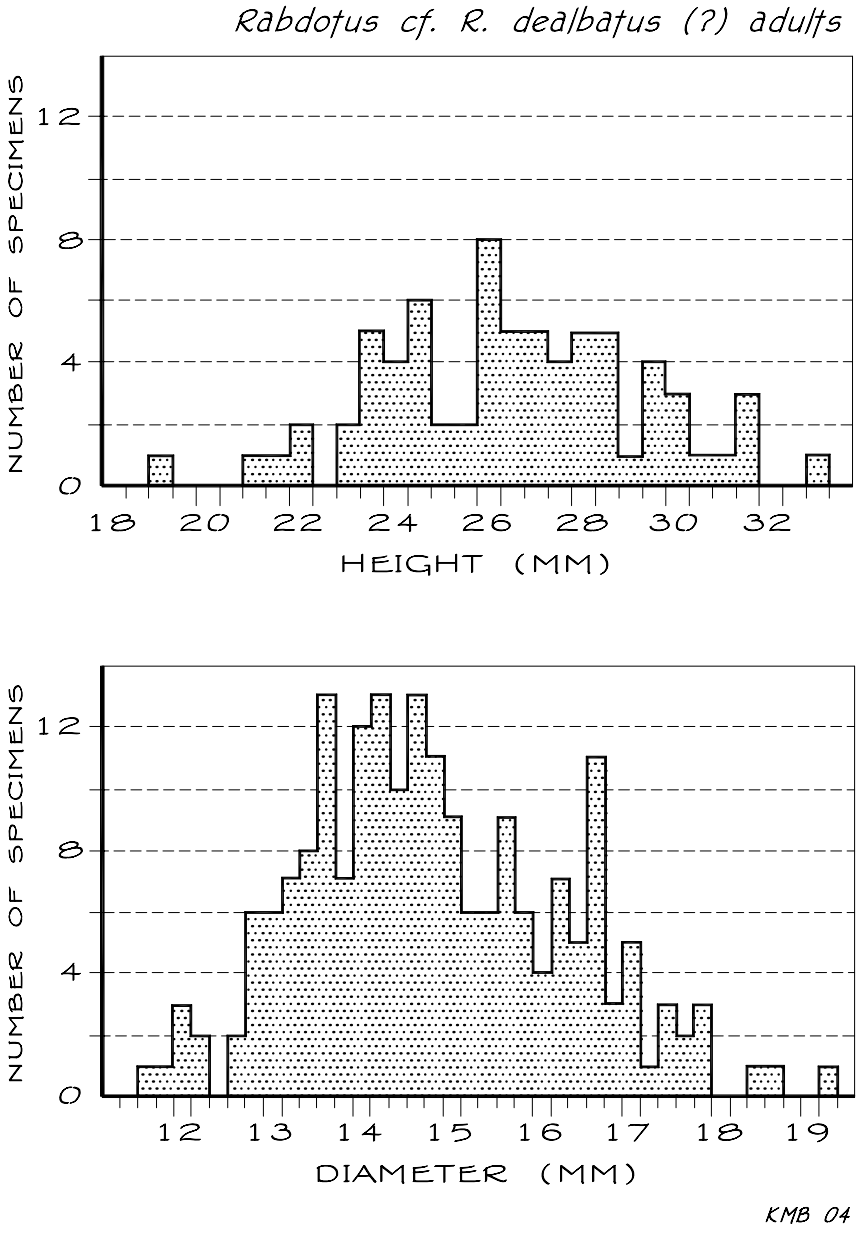


Figure 8.57. Histograms of *Rabdotus* Body Size, Adults Only. Top, height (N = 72); bottom, diameter (N = 199) for specimens from ¼-inch screen, all units except Unit 2 and N113 E98.

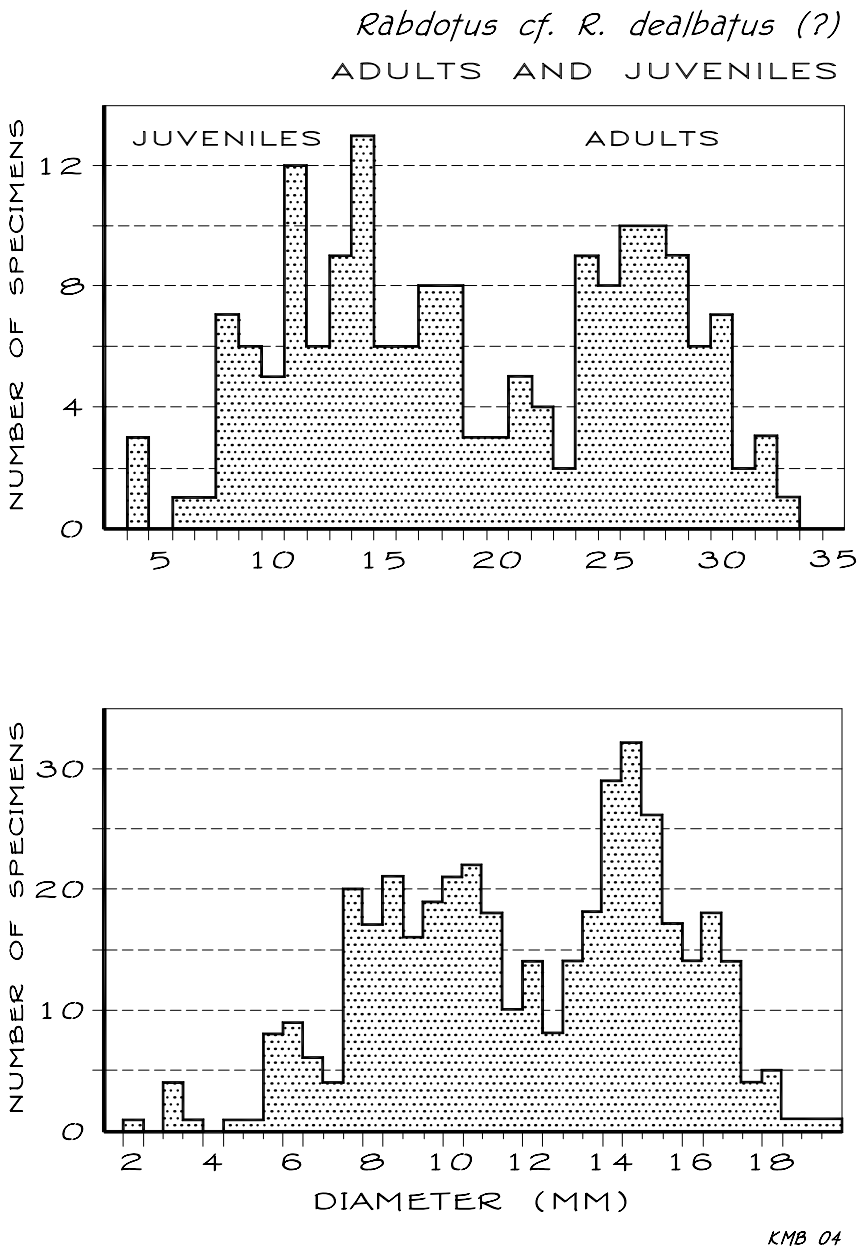


Figure 8.58. Histograms of *Rabdotus* Body Size, Adults and Juveniles Combined. Top, height (N = 173); bottom, diameter (N = 415) for specimens from ¼-inch screen, all units except Unit 2 and N113 E98.

Strobilops texasiana (Fig.8.59, 8.60), STRO

Matrix columns: 28 specimens
1/4-inch screen sample: 11 fortuitously recovered specimens
Body size: Microsnail, diameter 2.4 mm (Fullington and Pratt 1974:26), 1.9-2.0 mm (Burch 1962:66), 2.7 mm (1 specimen; Logsdon 1967:68)

This distinctive small snail is easily recognized, not readily confused with other species, and is fairly resistant to destruction, although only fortuitously retained on the 1/4-inch screen. The domed shape and exterior ribbing add structural strength to the shell. It has a somewhat discontinuous distribution in Maryland, Virginia, and South Carolina westward to Texas (Hubricht 1985:Map 103), where it is widely distributed in the eastern half of the state, extending westward in major river valleys (Fullington and Pratt 1974:Fig. 13), but not very common in south Texas. It is found around rotten logs, under loose bark, and in leaf litter (Fullington and Pratt 1974:26; Neck 1987a:316). Logsdon (1967:68) reported "*Strobilops texasiana* was found in drift debris at the Forney site (C), Talty (A) and the Reese Farm (C). Specimens were also collected from rotten logs at the Four Wyn Ranch (S)." Neck 1996:95) reports it from wooded areas. Coney and others (1982:93) found it significantly associated with the leaf litter microhabitat, although it also has a wide habitat breadth.

This species was moderately abundant in the Preiss Ranch drift sample (where 38 adults and 20 juveniles were recovered), and juveniles were also recovered from locality D-21 both in quadrat sampling and attached to downed wood in the live oak mott, as well as Goliad State park (Table 8.5). Although not abundant, it is widely distributed through the stratigraphic section in the bench deposits. This is one of the few species that is perhaps as common in the lower parts of the bench deposits as in the upper part, probably because of its durability. There are several specimens from stratum 2A, and two were

found in stratum 1 samples at 91.70-91.65 m and 91.60-91.55 m in the N110 E102 matrix column.

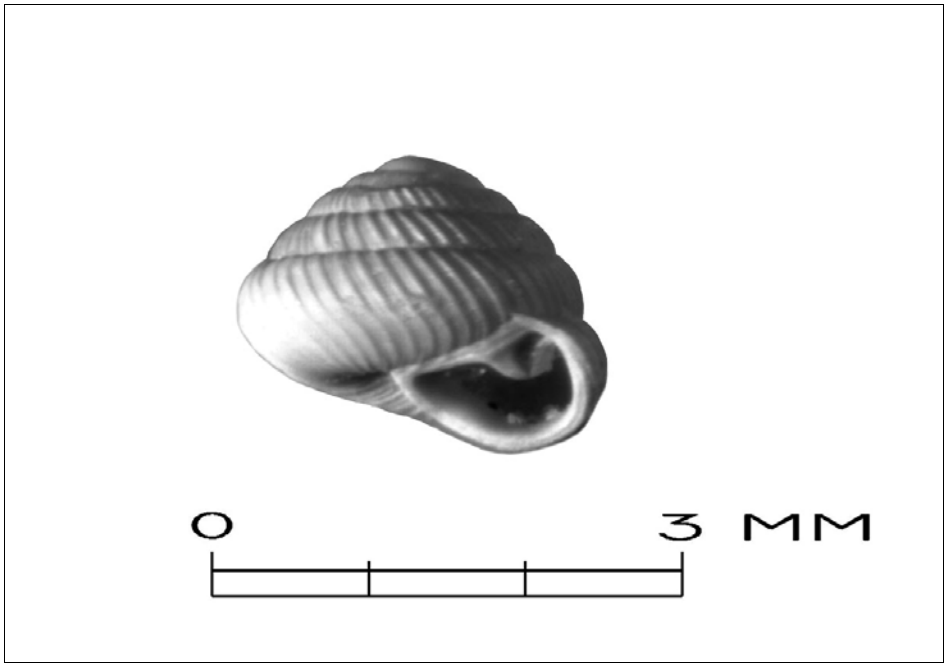
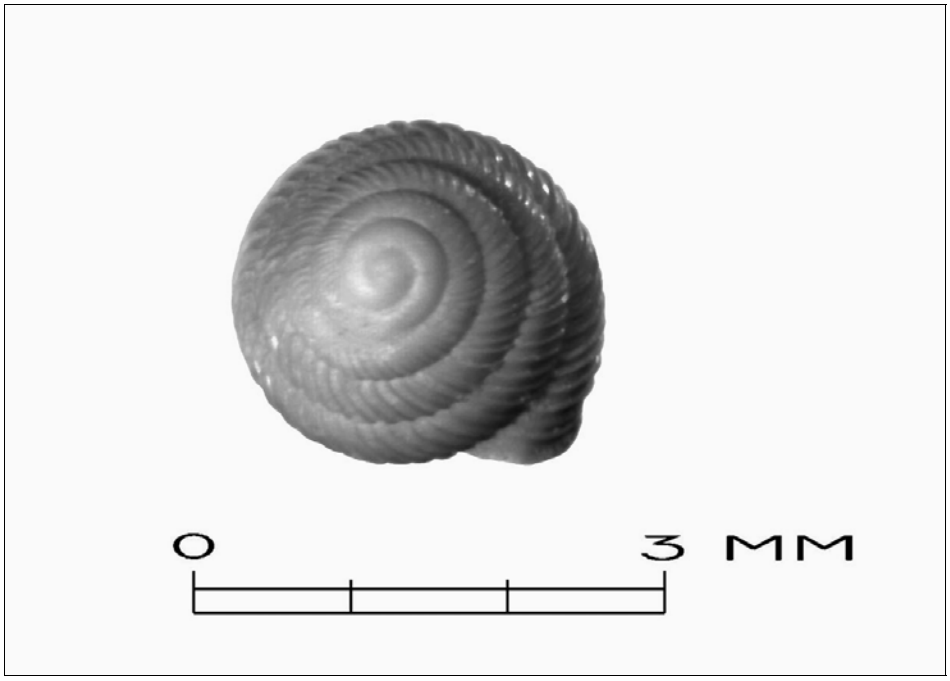


Figure 8.59. *Strobilops texasiana*, Adaxial View. Specimen from N109 E96 (92.90-92.85 m), Lot B-127.



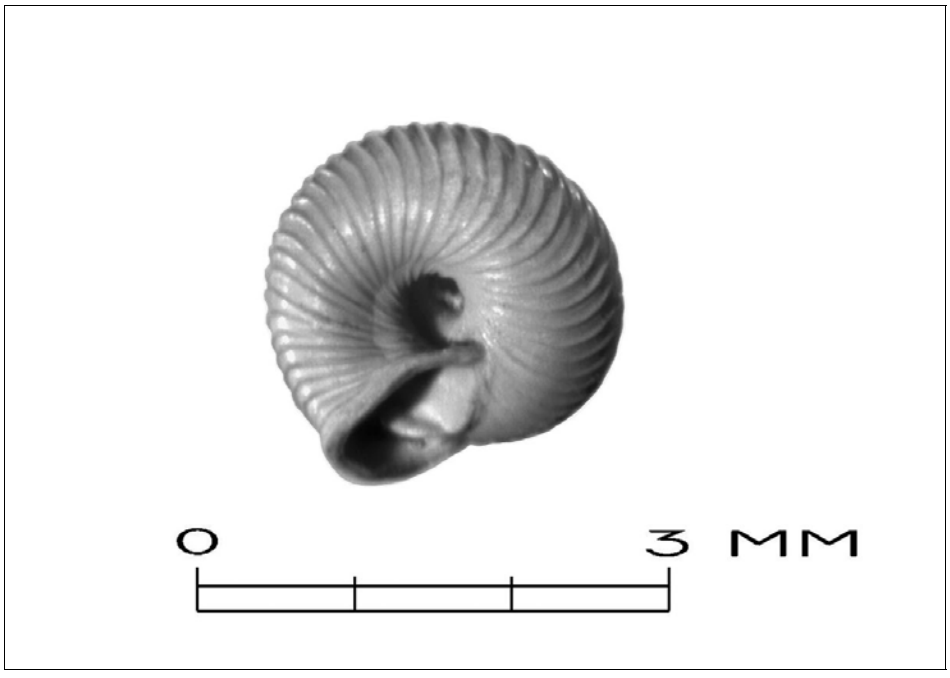


Figure 8.60. *Strobilops texasiana*, Additional Views. Top, apical view; bottom, umbilical view. Same specimen as previous photo.

This species has probably experienced significant eastward range contraction during the Holocene. According to Neck (1987a:Table 3), it was extirpated from the Lake Theo area in the Late Holocene. Archeological examples have also been found at the Rex Rodgers, Aubrey, Denton Creek, Wilson-Leonard, Mustang Branch, Kenyon Rockshelter, Winston's Cave, Richard Beene, Anthon, Smyth Crossing, and Gaulding sites, as well as 41 FT 193, 41 WM 118, 41 MM 340, 41 MM 341, 41 CH 56, 41 JK 53, 41 JK 66, 41 JK 78, and 41 MK 38 (Todd 2002:Table 1). It has been reported in paleontological context from Palo Blanco Creek in Brooks County (Hubricht 1962:3), the Fordyce Quarry in San Patricio County (Conkin, Conkin and Mason 1962), Stillhouse Hollow (Cheatum and Slaughter 1966), Wood Pit Pond and Channel (Slaughter et al. 1962), and the Clear Creek and Ben Franklin faunas (Cheatum and Allen 1963).

This species is interpreted as evidence of mature woodland, either well-drained upland woods as on the Preiss Ranch, or mature riparian woodland.

Zonitoides arboreus (Fig. 8.61), ZONA

Matrix columns: 4 specimens
1/4-inch screen sample: 3 fortuitously recovered specimens
Body size: Microsnail, diameter 5-6 mm (Burch 1962:117), 4-6 mm (Leonard 1959:122), 3.7-4.8 mm (Logsdon 1967:62)

This rather nondescript microsnail has a continent-wide distribution and is therefore presumably the most cosmopolitan and adaptable species found in the bench deposits. Although Leonard (1959:123) says it is colonial, only seven specimens were found in the bench deposits. Hubricht (1985:32) says "usually found on rotting logs and in floodplains, as well as upland woods" (see also Branson and Batch 1970:343; Hoff 1962:54). Leonard (1959:123) says "The habitat is notably varied. The snail is found in

wooded areas, on bluffs along streams, in grassland and under stones and boards. It is found most abundantly in and around loose bark of fallen trees." Logsdon (1967:61) says "*Zonitoides arboreus* was living primarily in rotten logs, and was taken from five sites. This species is common in habitats where other species were scarce or missing, being the only one taken from the sparsely vegetated site at Cedarvale, with its very low level of P_2O_5 and low nitrogen level. The organic matter was 2.2%." In Tennessee, Coney and others (1982:95) found it to have a wide habitat breadth, and associated with rotting log microhabitats. Leonard and Goble (1952:1044) report "*Z. arboreus* was common on the north facing slopes, where it was found under decaying logs and under leaf humus in an oak-elm association." The species was moderately common in the SPGS, where it occurred in densities of 49 and 144 individuals per square meter in mountaintop and rock ledge habitats (Wyckoff, Theler and Carter 1997:38).

The few examples found in the bench deposits are mostly in the upper part of the stratigraphic section, although one was found in the N110 E102 matrix column at 92.10-92.05 m, in stratum 2A. This species is regarded as an indicator of mature woodland with downed wood.

Archeological examples have been found at the Aubrey, Lubbock Lake, Denton Creek, Winston's Cave, Mustang Branch, Gaulding, and Guadalupe Bay sites, as well as 41 DT 59, 41 MM 340, 41 MM 341, 41 FT 193, and 34 Cd 257.

Figure 8.61.*Zonitoides arboreus*. Top, apical view; bottom, umbilical view. Specimen from N109 E96 (92.70-92.65 m), Lot B-10.

Unidentified slug (Fig. 8.62), SLUG

Matrix columns: none
1/4-inch screen sample: none
N109 E96 bulk matrix: 2 specimens
Body size: Micro-sized slug plate (soft tissue body size unknown)

Slugs are snails that lack an external shell, having only a very small, internal vestigial shell, called a *slug plate*. Because slugs are almost entirely soft tissue and the only hard part likely to be preserved is small and inconspicuous, they are rarely identified from archeological sites except when fine-screened matrix samples are examined by experienced archeomalacologists. No slug plates were recovered by Raymond Neck from the two matrix columns he examined, nor were any found while sorting snails from the 1/4-inch screen, but two slug plates were discovered while rough-sorting fine-screened bulk matrix from N109 E96 (93.08-93.00 m and 92.75-92.70 m; no lot numbers currently assigned).

The specimen from the 93.08-93.00 m level resembles a small longitudinally split clear quartz grain, but is in fact a calcareous slug plate. It is 2.6 mm long, 1.5 mm wide, with a maximum thickness of about 0.5 mm. It is convex on one side and unevenly flat on the other. Fine growth laminations can be seen near the edges under magnification. Although the unidentified slug that produced this slug plate was likely as large or larger than any of the large-bodied snail species (*Mesomphix*, *Anguispira*, *Rabdotus*), the slug plate itself is comparable in size to a microsnail, and must be recovered by the same techniques used for those minute species. The specimen from the 92.75-92.70 m level is almost identical (and is presumably the same species), 2.8 mm long and 1.7 mm wide.

Because slugs lack external shells, they are even more sensitive to water loss than other land snails, and are restricted to moist habitats. In archeological or paleontological projects, slug plates are most often recovered where cienega, spring-margin, or pond-margin deposits are sampled. Pleistocene deposits sometimes produce slug plates from the extinct giant Pleistocene slug, *Deroceras aenigma*, a member of the Limacidae (Taylor 1960:80; Plate 4, Figs. 14-16, 19-26; Leonard and Frye 1962:24; Plate II, Fig. 27).

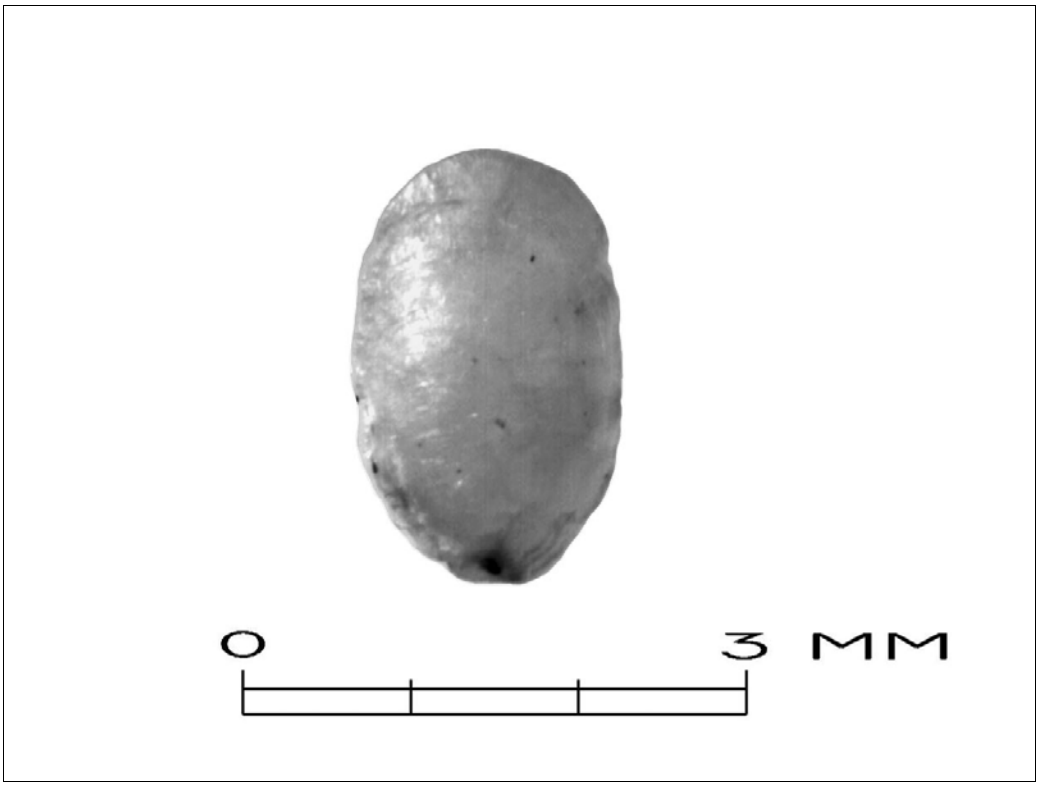


Figure 8.62. Slug Plate From Unidentified Slug. N109 E96 (93.08-93.00 m), bulk matrix passing ¼-inch screen. View of convex face.

Deroceras aenigma has been reported from the Burnham site (Theler 2003a), while *Deroceras laeve* has been reported from the Aubrey site, Lubbock Lake, Wilson-

Leonard (Shaw *et al*. 1998:Table 37-11), and the North Cove site in Nebraska (Stewart 1989), and *Deroceras* sp. has been reported from the Anthon and Denton Creek (Neck 1994a) sites. Both *Deroceras aenigma* and *D. laeve* have been reported from the Richard Beene site, where the former appears only in sample 30, and the latter in samples 25, 28, and 30 (Neck 1992:Table 4) near the bottom of the stratigraphic section. McGee (1965:162) regards *Deroceras laeve* as introduced to Texas from more northerly parts of the US, and lists *Philomycus carolinianus* as the only native slug, but the archeological evidence seems to dispute that position.

Slugs are probably much more common in wetter, cooler climates like the northeastern or northwestern US than in Texas. In central Maine, for example, 35% of the terrestrial gastropods collected by Martin (2000:51) were slugs. In Texas, slugs are familiar to urban dwellers mainly because of the artificially humidified plant-rich habitats we voluntarily provide for them. They occur in arid climates, such as New Mexico, but in the wild are usually found only around springs, streams, or wet montane meadows (Metcalf and Smartt 1997:51). Even more so than other land snails, they use behavioral adaptations to restrict water loss, foraging mainly at night during periods of high humidity.

Slug plates in archeological sites can be taken as indicators of consistently wet conditions, but because they are so easily overlooked in sampling, their absence should not necessarily be taken to indicate aridity.

AMPHIBIOUS SNAILS

Catinella vermeta (Fig. 8.63), CATV

Matrix columns: 5 specimens
1/4-inch screen sample: 8 specimens
Body size: Small to medium-bodied, median height 5.4-9.5 mm (range, 4.15-12.6; Franzen 1982:Table 1), height 7-13 mm (Burch 1962:67), both as *Succinea avara*; 10.8-13.3 mm (Hubricht 1961:61, as *Catinella texana*), 6.5-14.5 mm (Logsdon 1967:80)

This amphibious snail is a member of the family Succineidae, which are said not to be identifiable except by soft-tissue dissection. The taxonomy of these snails is very convoluted. The generic names *Succinea*, *Catinella*, and *Quickella* have all been applied in the past and will be found in the literature. The following combinations (and others) appear:

Catinella vermeta
Catinella avara
Catinella texana
Quickella vermeta
Succinea avara

The definitive study is by Franzen (1982), who provides metric statistics for specimens from the southern Plains. Adults are typically about 8 mm high and 4.5 mm in diameter, but vary considerably. Regarding habitat preference, Hubricht (1985:16, *as Catinella avara*) says "Usually found on wet ground in low, wet places, floodplains, margins of ponds, marshes, and swamps in both shady and sunny situations." Logsdon (1967:80) says "*Catinella vermeta* was found at six sites; being collected from fence posts, where it was aestivating, under leaves, under *Sorghum halepense* cover, and on the stems of *Cyperus setigerus*, which were growing near a pond." This species is sometimes found under logs near streams (Cheatum and Burt 1931:338).

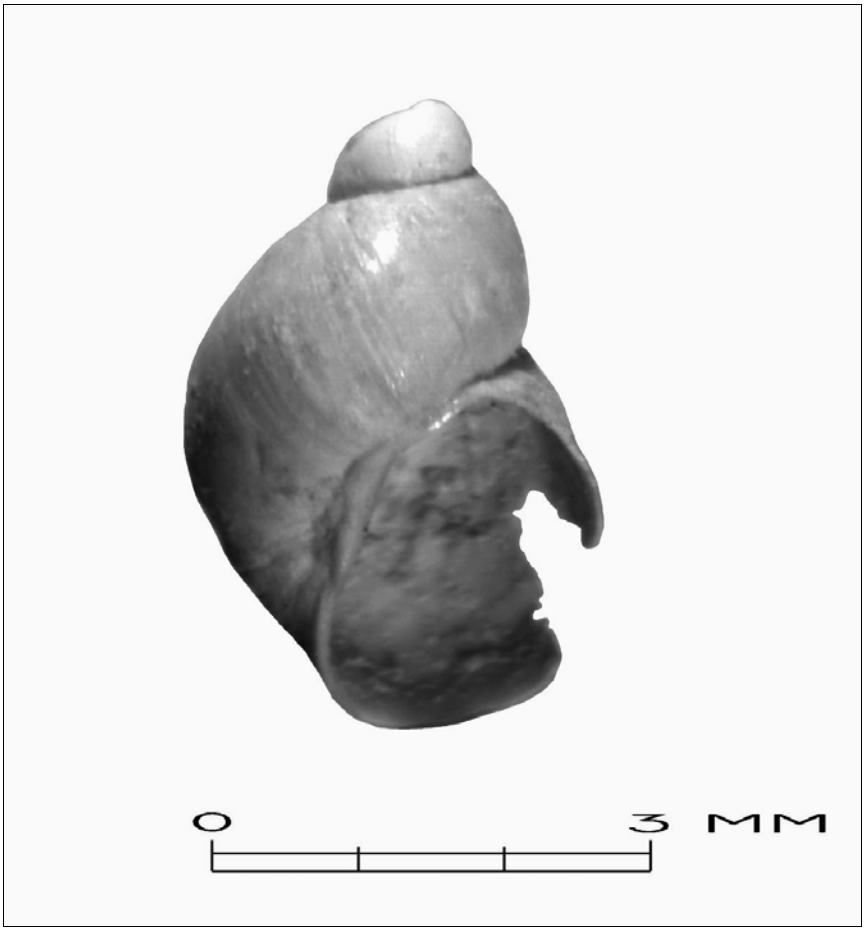


Figure 8.63. *Catinella vermeta*, Adaxial View. N109 E96 (93.08-93.00 m), Lot B-125. Larger of two specimens in this lot.

Branson (1963:80) says, “This form is nearly always found in moist areas, sometimes actively entering the water… Its food consists primarily of algae, fungi, and molds of various types.” They are widespread in Texas (McGee 1965:100).

The succineids are really amphibious snails, but they have been variously classified as terrestrial or aquatic by previous authors. I have seen them most often on open damp ground in shallow swales in otherwise flat ground, but they are also known to

estivate on trees. These are very thin-shelled, fragile snails. Because they stay close to water but avoid swift flows, they do not need thick shells to retain moisture or resist strong currents. Consequently, they are fragile and are likely to be underrepresented in archeological collections, even if they are large enough to be retained on a 1/4-inch screen. Most of the specimens from the bench deposits are from near the top of the stratigraphic section, where carbonate cementation is less pronounced and shell breakage is probably less severe.

These snails are typically marsh, cienega, spring-margin or stream bank snails. Since the bench deposits are interpreted as a spring margin site, much greater representation would be expected if the shells were more durable. The low frequency of this species is assumed to be at least partly due to taphonomic deletion.

Succineids are often found (at least in low numbers) in archeological sites, but are likely to be listed by a wide variety of names (probably far more names than actual species are present), or often just as “Succineidae”. This species is found at the Aubrey site (as *Catinella avara*) and perhaps at the Hajny Mammoth site (Branson 1992, as *Quickella* cf. *vermeta*).

Pomatiopsis lapidaria (Fig.8.64), PLAP

Matrix columns: 5 specimens
1/4-inch screen sample: none
Body size: Microsnail, modal height for adults 4.5-6.0 mm (maximum, 7.0-8.5 mm; Dundee 1957:13); height 6.75 mm (LaRocque 1968:413)

This small, conical operculate (prosobranch) snail is widely distributed in the eastern US, in the Mississippi River basin, and elsewhere but is apparently now

extirpated in Texas (Fig. 8.7, based on Hubricht 1985:Map 11). Burch and Van Devender (1980:Fig. 44) show isolated occurrences in New Mexico and the Texas panhandle, but the nature of the localities is not clear. Neck (1990a) does not list it. Branson, Taylor, and Taylor (1962:284) list it for Oklahoma only as a fossil species. It is sexually dimorphic; females (modal size 5-6 mm) are slightly larger than males (modal size 4.5-5.0 mm; Dundee 1957:13). Males are slightly more slender, with a slightly higher whorl count. Adults can presumably be anywhere from about 4.0-8.5 mm high; the lifespan is about three years. The most comprehensive study of this species is by Dundee, who says "*Pomatiopsis lapidaria* is found in a variety of habitats such as marshes, wooded flood plains of small creeks, grassy hummocks in low, wet pastures… and in upland artesian-fed marshes. The features common to all *P. lapidaria* habitats seem to be: (1) a very moist substratum with enough sand to prevent it from becoming muck, (2) shade, (3) fresh water. As with all of these general descriptions of habitats, one must keep in mind the seasonal factor – that these habitats are drier at certain times of the year" (Dundee 1957:11-12). The species is colonial, shifting position seasonally to maintain proximity to moisture, and estivating with the operculum closed in dry weather. Maximum movement during the lifespan of the individual is about six feet (Dundee 1957:14).

Hubricht (1985:4) says, "A calciphile. This species has often been referred to as amphibious or even aquatic. But, having collected it at more than 300 localities, it is my opinion that, were it not for its aquatic affinities, it would have been accepted as a land snail without question. Found crawling on damp mud on floodplains, but usually above the normal high-water line; also on talus slopes, in ravines, and on mountainsides. During winter floods it may be washed into streams, where it may live for some time. During warmer weather it may climb up on plants and tree trunks to escape the water." In

Kentucky, according to Kaplan and Minckley (1960:65) it is “Abundant; all stations. We collected living specimens of this species from the bottom of the creek in March and December. The latter occurrence was in a bottom sample obtained from 5 feet of water. The species was also found living along the stream banks, sometimes as far as 40 yards from the creek.” The species has been documented from hummocky swamps (Hubricht 1960:33) and seepage areas (Van der Schalie and Getz 1962). Ameel (1938:703) also summarizes habitat preference.

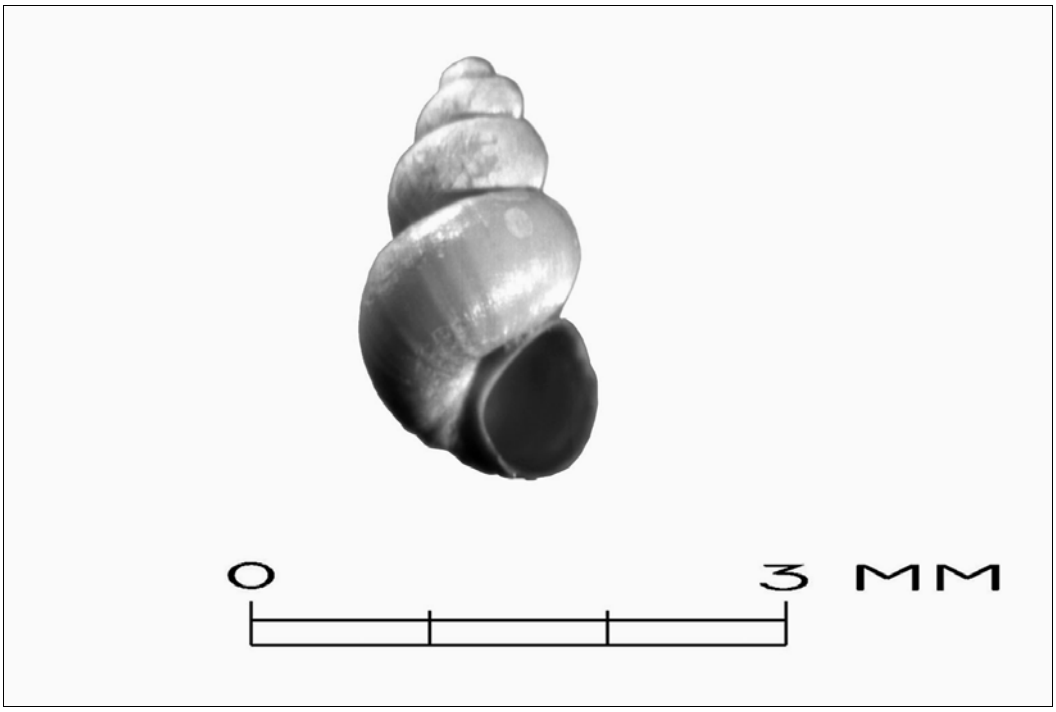


Figure 8.64. *Pomatiopsis lapidaria*, Adaxial View. Specimen from snail matrix column, N110 E102 (92.20-92.15 m, sample 14.

It is clear from the sources consulted that this stenotopic species prefers damp, marshy terrain but can live submerged in water for extended periods of time without

making an effort to escape. Five examples of this species were recovered from the two matrix columns analyzed by Neck – a single occurrence in each of five excavation levels, all of them below 92.25 m in elevation. These are all in strata 1, 2A or the very lowest part of stratum 2B.

Large numbers of this species were recovered from the pond margin (and smaller numbers from the pond axis) at the Aubrey site (Neck 2001:Tables 7.2, 7.3). Fairly large numbers were also obtained from the Domebo site (Cheatum and Allen 1966:Table 2). A few specimens were recovered from Wilson-Leonard (Shaw *et al*. 1998:Table 37-6). Paleontological occurrences include one locality in Caddo County, Oklahoma (Branson, Taylor and Taylor 1962), several Texas localities such as the Byers locality in Clay County (Allen and Cheatum 1961), Stillhouse Hollow (Cheatum and Slaughter 1966), the Clear Creek fauna (Cheatum and Allen 1963), Cooper Reservoir (Slaughter 1964), and a nameless locality in Comal County (Hubricht 1962:1). The rarity of this snail in archeological contexts perhaps indicates it is a useful Pleistocene marker species in Texas.

AQUATIC SNAILS

As in most archeological sites, there are relatively few aquatic snails in the bench deposits, but those present are quite informative. There are two prosobranch species, *Cincinnatia integra* and *Valvata tricarinata*, and the remaining species are all pulmonate snails. Prosobranch snails are gill-breathing, and cannot tolerate poorly oxygenated water. These probably came from a nearby habitat with clear, perennially running water, perhaps a spring run located close to the site. The remaining species are pulmonates, or lung-breathing snails capable of surviving on poorly oxygenated water, often in temporary ponds or seasonally drying drainages. Some of these snails have varices, or growth interruption features visible on the shell that suggest either overwintering or seasonal disruption of the aquatic habitat. These probably came from Coleto Creek itself. All of the aquatic snails, regardless of origin, were probably deposited by periodic overbank flooding of the creek. Most of these aquatic species are widely distributed across the North American continent, but *Valvata tricarinata* is extirpated in Texas.

Biomphalaria obstructa, BIOO

Matrix columns: 3 specimens
1/4-inch screen sample: none
Body size: Microsnail, maximum diameter 11 mm (Fullington 1978b:182)

This planorbid (pulmonate) genus is found in tropical regions from Africa to the Caribbean, South America, and the Gulf of Mexico region in the US. In Texas, the species present is usually classified as *Biomphalaria obstructa*, although it has also occasionally been classified as *Biomphalaria havanensis* (Burch and Tottenham 1980:198). *Biomphalaria havanensis* may be as much as 10-13 mm in diameter

(Thompson 1984:72). In Texas, it is widely distributed wherever suitable aquatic habitats are found and has been previously reported from the counties of De Witt and Victoria (see also Lindholm 1979:31). Fullington (1978b:183) says "I have collected living specimens from mud in a dry stock tank in Brewster County and from clear Hill Country streams." It occurs as far north as Garza County and Erath County. This was the most common aquatic species found in the Preiss Ranch drift sample (Table 8.8. The shell itself is small, flat, and discoidal in shape. According to Malek (1969:189),

> "Their distribution in Louisiana coincides with bottomland hardwoods, cypress and tupelo (*Nyssa*) as well as with the delta and subdelta mud flats and their freshwater marshes…. the habitats of these snails in Louisiana are clear or slightly turbid waters with mud banks and humus bottoms…. There was a seasonal temperature variation of 20° C (9° C - 29° C). Freezing or near freezing temperatures were also occasionally recorded during 1961 and 1963. A maximum temperature of 32° C was measured in certain microhabitats."

One of the specimens from the N109 E103 matrix column comes from near the top of the column at 92.85-92.80 m, while the other two come from the N110 E102 column at 92.15-92.10 and 92.05-92.00 m, in stratum 2A.

A couple of examples of this species are reported as *B. havanensis* from the Wilson-Leonard site (Shaw *et al*. 1998:Table 37-6). Other examples of *B. havanensis* are reported from 41 CC 112 (Treece 1992) and 41 WM 312 (Voellinger and Gearhart 1987). It has also been reported from the Sleeper site (Neck 1991), although because the fine-screen samples were washed with creek water, it is unclear whether the specimens from the fine-screen samples might be modern contaminants. Bequaert and Miller (1973:207) list *Biomphalaria havanensis* as "a common Pleistocene fossil in Texas and Louisiana."

Cincinnatia integra (Fig. 8.65), CINI

Matrix columns: 52 specimens
1/4-inch screen sample: 8 specimens
Body size: Microsnail, maximum height 6 mm (Fullington 1978b:36); 4.0-6.0 mm (Clarke 1973:241-242)

This prosobranch species was formerly classified as *Cincinnatia cincinnatiensis*, but Hershler and Thompson (1996) have re-examined the taxonomy and classified it by the original name, *Cincinnatia integra*. It may also appear as *Amnicola integra* in some of the older literature. The common name is "Midland Siltsnail." Fullington (1978b:37) points out that it is a fairly common Pleistocene fossil in north Texas, but he could find no definite living populations in the state and tentatively regarded it as extirpated in Texas. He remarked that "However, it probably will be found alive in the streams of northeastern or central Texas… it is strongly suspected that relict colonies might exist in some northern Hill County streams." Seven specimens were found in the Preiss Ranch drift sample (Table 8.8), and if these are not subfossil, possibly they indicate the presence of a recent population in the Coleto Creek basin. Hershler and Thompson (1996:50, Fig. 70) show the species as widely distributed in the Mississippi River basin and Midwest and present across the south-central part of Texas in an irregular band from Chambers County in the east to Kinney County in the west. They list it as occurring in Cardenas Creek, Goliad County, Ripley Lake and Garcitas Creek (Victoria County) and the Guadalupe River. In Kansas, it occurs in the eastern half of the state, but may be declining (Angelo, Cringan and Fry 2002:249).

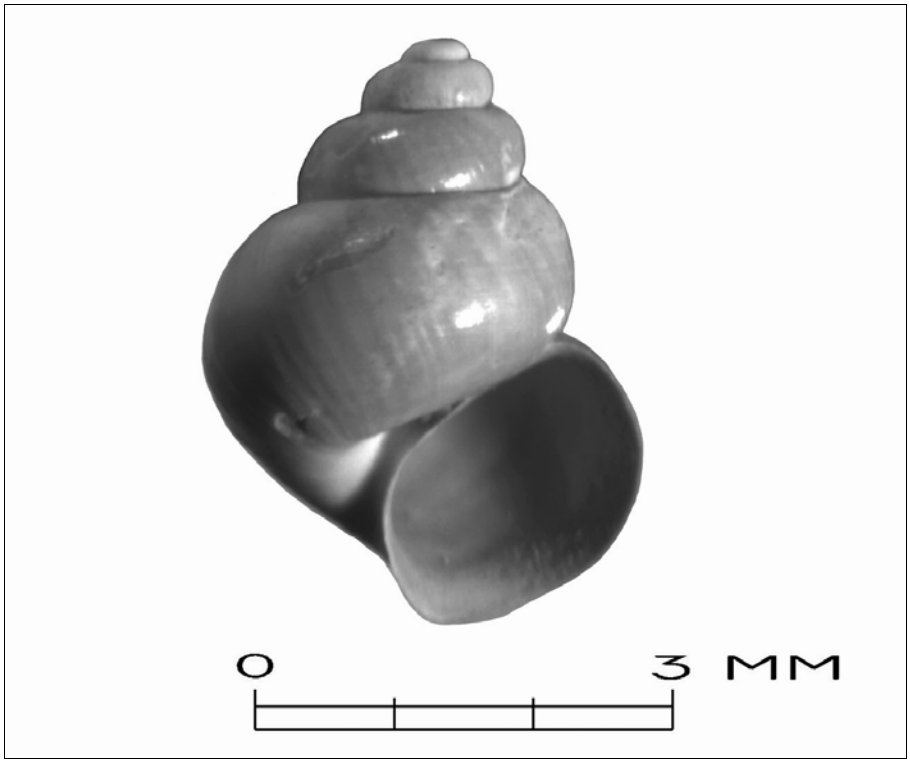


Figure 8.65. *Cincinnatia integra*, Adaxial View. From N109 E103 matrix column (92.00-91.95 m), coarse fraction.

These are small, broad, conical snails with large circular apertures. They could possibly be confused with a variety of other small conical snails, including juvenile *Rabdotus*. Fullington (1978b:37) says "*Cincinnatia cincinnatiensis* inhabits streams, usually with moderate to slow flow. The substrate may be soft mud or sand-gravel, always with abundant algae and macrophytic vegetation present… The food is chiefly diatoms." Leonard (1959:34) says "In Lone Star lake, *A. integra* was found living on mud bottom in quiet shallow water near the mouth of a small creek emptying into the lake. In this habitat the water was somewhat turbid and contained large masses of floating an

partly submerged algae. In Shoal Creek it was found living on ooze-covered gravel bottom in clear quiet water about one foot deep." Branson (1961b:42) says "in Oklahoma they have only been found in sand or gravel-bottomed streams possessing abundant aquatic vegetation, and in running water." In Canada, the species has been found in small rivers (slow to moderate current) to large lakes (Clarke 1973:242-243).

This species has a very interesting stratigraphic distribution in the bench deposits (Table 8.18). In the N109 E103 matrix column, it occurs in moderate numbers, but only below the base of stratum 2B (92.25 m and below). In the N110 E102 matrix column and in other units where specimens were fortuitously recovered from the 1/4-inch screen, it is more widely distributed, with occurrences scattered all the way from stratum 1 to stratum 2D.

This species is occasionally recovered from archeological contexts. It has been found at 41 MK 38 (Todd 2002:Table 1), 41 CH 56 (Weinstein and Whelan 1987), and the Denton Creek, Richard Beene and Wilson-Leonard (Shaw *et al*. 1998:Table 37-8) sites. Two specimens were found at the Smith Creek Bridge site (Brown 2002:252).

Table 8.18. Provenience of *Cincinnatia integra* Specimens.

1/4-inch Screen Sample

N109 E103		
92.90-92.85	Stratum 2D	1
92.15-92.10	Stratum 2A	1
N111 E101		
92.65-92.60	Stratum 2C	1
N109 E96		
93.08-93.00	Stratum 2D	1
92.85-92.80	Stratum 2D	1
92.45-92.40	Stratum 2C	1
92.40-92.35	Stratum 2C	1
92.15-92.10	Stratum 2A	1

N109 E103 Matrix Samples

92.25-92.20	Stratum 2B	10
92.20-92.15	Transitional	4
92.15-92.10	Stratum 2A	6
92.10-92.05	Stratum 2A	3
92.05-92.00	Transitional	2
92.00-91.95	Stratum 1	8
91.95-91.90	Stratum 1	6

N110 E102 Matrix Samples

92.90-92.80	Stratum 2D	2
92.80-92.75	Stratum 2D	1
92.70-92.65	Stratum 2C	1
92.30-92.25	Stratum 2B	3
92.25-92.20	Stratum 2B	3
92.05-92.00	Stratum 2A	1
91.90-91.85	Calcrete	1
91.85-91.80	Stratum 1	1

Gyraulus parvus (Fig. 8.66), GYRP

Matrix columns: 11 specimens
1/4-inch screen sample: 8 fortuitously recovered specimens
Body size: Microsnail, maximum diameter 5 mm (Fullington 1978b:189); 1.5-4.5 mm (Clarke 1973:401)

This very small planorbid (pulmonate) snail is widely distributed across the entire continent and is rather widely distributed in Texas as well, although there seem to be no recent reports in or near Goliad County. It can be confused with related species such as *Gyraulus circumstriatus*, or other small planorbids such as *Micromenetus dilatatus*. It has a fairly fragile, thin-walled shell and could be underrepresented due to taphonomic deletion. This species is characteristic of water bodies with dense aquatic vegetation, often with mud bottoms (Fullington 1978b:190; Dawley 1947:694; Dexter 1956:367; Tuthill, Clayton and Laird 1964:354). Clarke (1973:403) collected it in lakes, vernal and permanent ponds, backwater areas of streams, swamps, and rivers and creeks; bottom types were diverse, but mud occurred in 60% of the localities. In lotic habitats, current was slow to moderate. According to Leonard (1959:61), "*G. parvus* in Kansas is common in natural and artificial lakes and occasionally in quiet pools in stream beds… The species is frequent on or among aquatic plants such as *Chara*, *Typha*, *Spirogyra*, and duckweed, and occurs on submerged blades of living and dead grasses or on dead tree leaves in water." In Alberta, it is more common in lentic (lakes and ponds) than lotic (rivers and creeks) habitats, and is found in water with a mean pH of 8.8 (range, 7.5-10.7; Prescott and Curteanu 2004:31). It is common in the slough and Spring Lake at San Marcos, less so under algae and rocks in the San Marcos River (Lindholm 1979:31). It has also been found in playa lakes in the Panhandle, often on mud bottoms (Neck and Schramm 1992:207). It has also been found in deep water in the Great Lakes (Burch and Jung 1987:267).

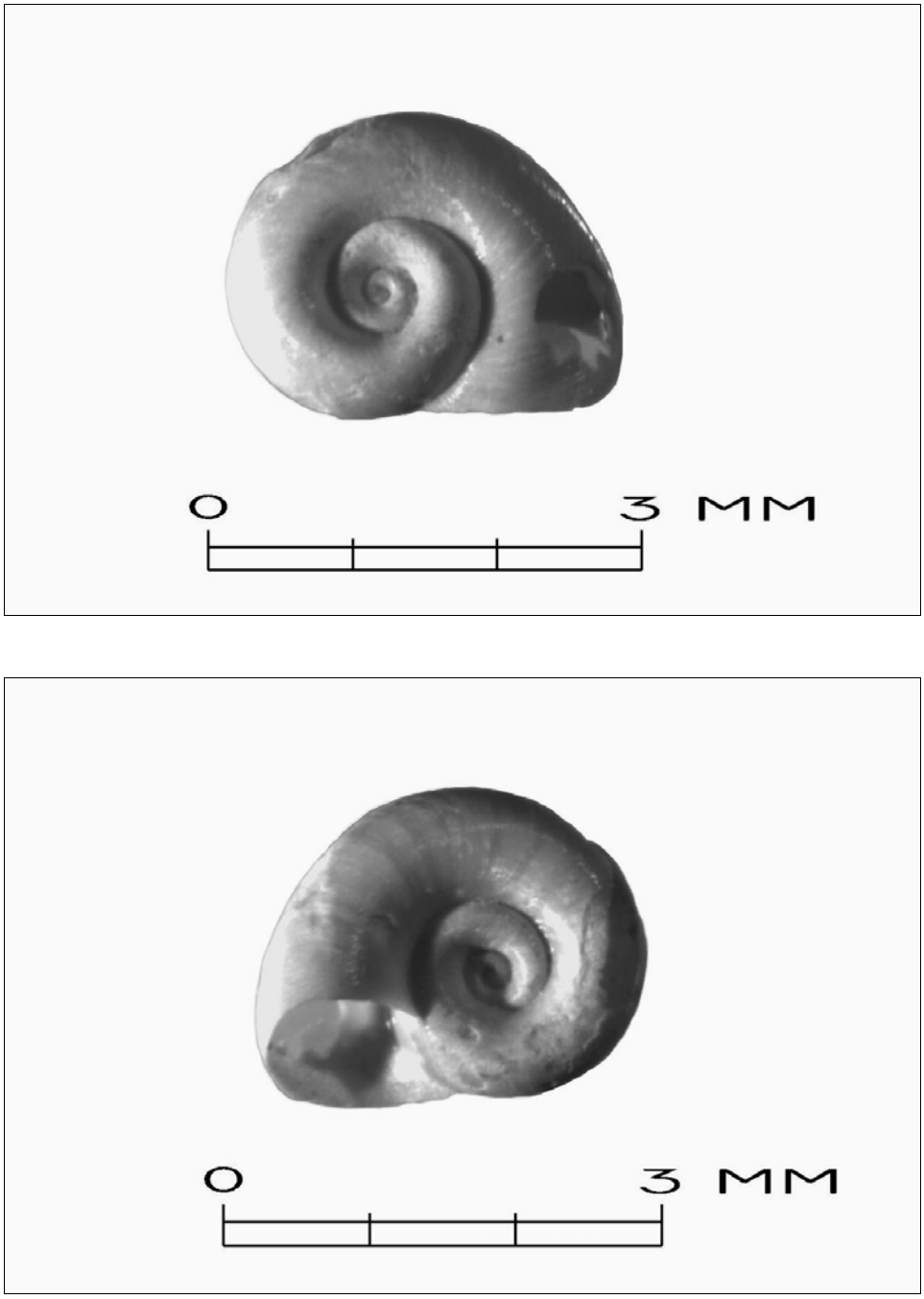


Figure 8.66. *Gyraulus parvus. Top*, apical view*; bottom*, umbilical view. N109 E103 (92.65-92.60 m), Lot B-11.

In the bench deposits, the small numbers of *Gyraulus parvus* recovered are scattered throughout the stratigraphic section from stratum1 to stratum 3, with no particular concentration at any one level. Other archeological examples have been found at the Aubrey site, Domebo site, Rex Rodgers, Lubbock Lake, 41 FS 6 (Wulfkuhle 1986:405), 41 MK 38 (Todd 2002:Table 1), Lake Amistad, 41 TG 91, 41 TV 368, Aquilla Lake, various sites (41 WM 56, 41 WM 73, 41 WM 304) on the San Gabriel River (Fullington and Fullington 1982b), Blockhouse Creek, the Sleeper site, and 41 CC 112 (references for most of these are in Brown 2002:256), as well as the Lehner and Murray Springs sites in Arizona (Bequaert and Miller 1973:205).

At Berger Bluff, this species is taken as an indicator of fairly slow (perhaps silty or turbid) current conditions in Coleto Creek, probably with a muddy bottom and abundant aquatic vegetation.

Helisoma anceps (Fig. 8.67), HANC

Matrix columns: none
1/4-inch screen sample: 17 specimens
Body size: Medium to large-bodied, maximum diameter 17 mm (Clarke 1973:428); 9-15 mm (Thompson 1984:73)

Although Clarke (1973:429) lists mean diameters of about 9-12 mm for *Helisoma anceps*, most of the specimens from the bench deposits are slightly smaller. Herrman and Harman (1975:8) report diameters of 9.5-10.4 mm at the end of the first year of growth in New York. This pulmonate snail is very closely related to *Planorbella trivolvis* and is difficult to distinguish from juveniles of that species. Distinguishing characters for *H. anceps* are 1) small size, 2) carination of the body whorl on both faces, 3) a somewhat angulated aperture, compared to the evenly rounded aperture in *P. trivolvis* (see

Thompson 1984:Figs. 158-160). In some of the older literature, this species is listed as *Helisoma antrosa*. Raymond Neck did not identify any examples of this species in the matrix columns, but several that seem to fit the definition occur in the quarter-inch mesh sample, and several specimens from the matrix columns that Neck identified as *Planorbella trivolvis* seem to me to fit the definition of *Helisoma anceps* better.

Helisoma anceps is a fairly common species, both in present-day water bodies and in archeological deposits, although only one specimen was found in the Preiss Ranch drift sample. Fullington (1978b:196) says

> In Texas, *H. anceps* occurs principally in streams and along upper river stretches and usually not in large populations per locality. The presence of aquatic vegetation does not appear to be necessary. It seems to especially be prevalent in gravelly, riffle areas. Analysis of all available Texas *Helisoma anceps* specimens revealed that the distribution of living populations is spotty while the fossil distribution is quite extensive and numerous. This may be an indication that *H. anceps*, actually a more northern, cooler climate species, is being extirpated from this area by current drying trends.

Lindholm (1979:31) found these in slackwater areas in the San Marcos River floodplain. In Oklahoma, Branson (1961b:61) says "This unmistakable species is widely divergent as to its habitat requirements. It may be found in rapidly flowing creeks and rivers, in back waters, or in ponds. it seems to prefer copious vegetation but there seems to be no obvious substrate specificity."

In Kansas, "*H. antrosa* was found less commonly than *H. trivolvis* 'apparently because of a closer restriction to habitat. It prefers clean running water…' In Kingman County, the habitat has been recorded as shallow streams with wide, sandy and sandy-loam flood plains, the tree flora consisting mainly of cottonwood and willow" (Leonard

1959:60). In Minnesota, it is common in both lakes and rivers (Dawley 1947:694; Tuthill, Clayton and Laird 1964:354). In North Dakota, it occurs in intermittent and small perennial streams (Cvancara 1975:Table 1).

In the bench deposits, examples of this species are more or less evenly distributed from stratum 2A to stratum 2D. In unit N109 E103, they are mostly found near the base of the unit, but in N111 E 101, the opposite is true. Diameters range from 4.3 to 15.3 mm, although many have chipped apertures. Mean diameter is 8.66 ± 2.56 mm. At least four specimens have varices, or growth arrest features visible on the shell. This indicates either some sort of disruption (perhaps seasonal drying) of the aquatic habitat or hibernation during overwintering. In three cases, the varix is close to the aperture, suggesting the event was followed shortly thereafter by the death of the individual. A scenario involving seasonal drying of the water body, followed by a flood event that deposited the snail on the floodplain surface might be indicated. Or the varix might simply indicate winter hibernation. In the fourth case, the varix is faint and well back from the aperture, suggesting considerable time had elapsed between the disruptive event and deposition of the shell.

Helisoma anceps is occasionally found in archeological sites, but is probably less common than *Planorbella trivolvis*. A small number were found at the Smith Creek Bridge site (Brown 2002:252-253). Others have been found at the Aubrey site, the Richard Beene site, Lubbock lake, Justiceburg Reservoir, Lake Amistad, Aquilla Lake, the Shrew site, Blockhouse Creek, Skyline Shelter, the Sleeper site, various sites at O. H. Ivie Reservoir (references for most of these are in Brown 2002:253).

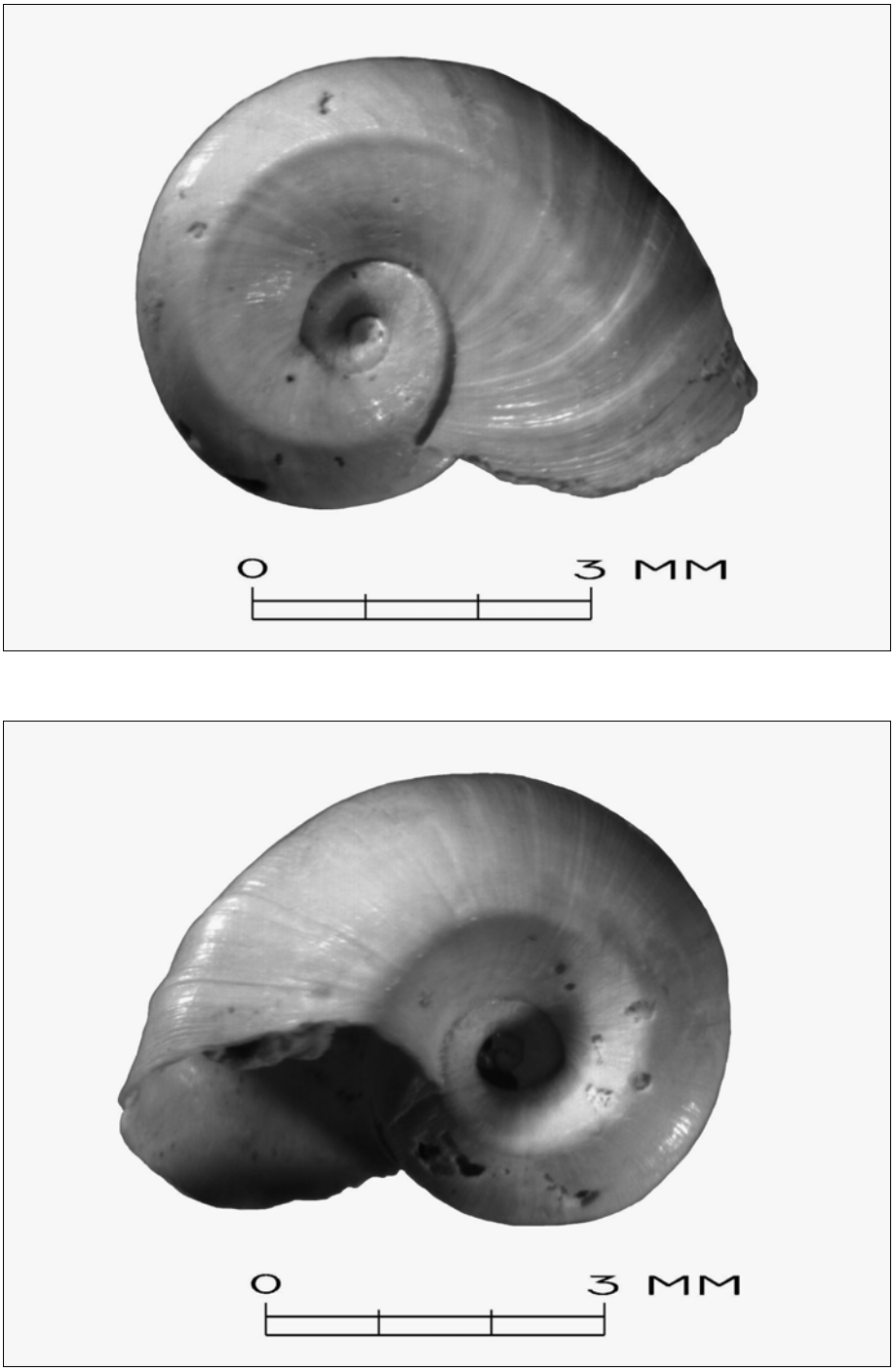


Figure 8.67. *Helisoma anceps*. *Top*, apical view; *bottom*, umbilical view. N109 E96 bulk matrix, coarse fraction (92.70-92.65 m). Juvenile, largest of three specimens in this lot.

Lymnaeidae, cf. *Fossaria* sp. (?) (Fig. 8.68), LYM

Matrix columns: none
1/4-inch screen sample: 1 fortuitously recovered specimen
Body size: Microsnail, measured height 4.6 mm

The 1/4-inch screen sample from the uppermost level (93.14-92.75 m, Lot B-111) in unit N112 E97 contains a single small specimen that appears to be a member of the Lymnaeidae (a pulmonate family). It resembles some species of *Fossaria*, such as *Fossaria obrussa* or *Fossaria dalli* (compare with Burch and Tottenham 1980:Figs. 570, 575, 588; Fullington 1978b:Figs. 10, d; 11, f; La Rocque 1968:Plate 9, Figs. 8, 10-12). The maximum height is 4.6 mm, diameter 2.7 mm, aperture height 2.8 mm and aperture width 1.9 mm. It has a large, oval aperture that accounts for about 61% of the shell height, and has a somewhat rounded (not sharply pointed) apex. Unfortunately, there are many species of *Fossaria*, and they are highly variable in shape, even within a species. Fullington (1978b, see discussion on pages 150-151) recognizes only two species of *Fossaria* in Texas, *F. obrussa* and *F. dalli*. These often appear in the older literature under the generic names *Galba* and *Lymnaea*. These species of *Fossaria* are found in shallow water or ponds with mud bottoms, bordered by sedges and cattails (Leonard 1959:52, 56) or marshy areas (La Rocque 1968:475). Clarke (1973:289) found *F. dalli* in lakes and rivers with slow to moderate current and variable bottom composition.

The single specimen from the bench deposits probably indicates a slackwater or slow current muddy habitat similar to that occupied by *Gyraulus parvus*. Jokinen (1978) reports that many of the Lymnaeidae estivate out of the water, on or under mud or soil, on trees or aquatic vegetation. She found that juvenile *Lymnaea elodes* would migrate out of receding pond water and spend 3-4 months in late summer and fall on dry objects.

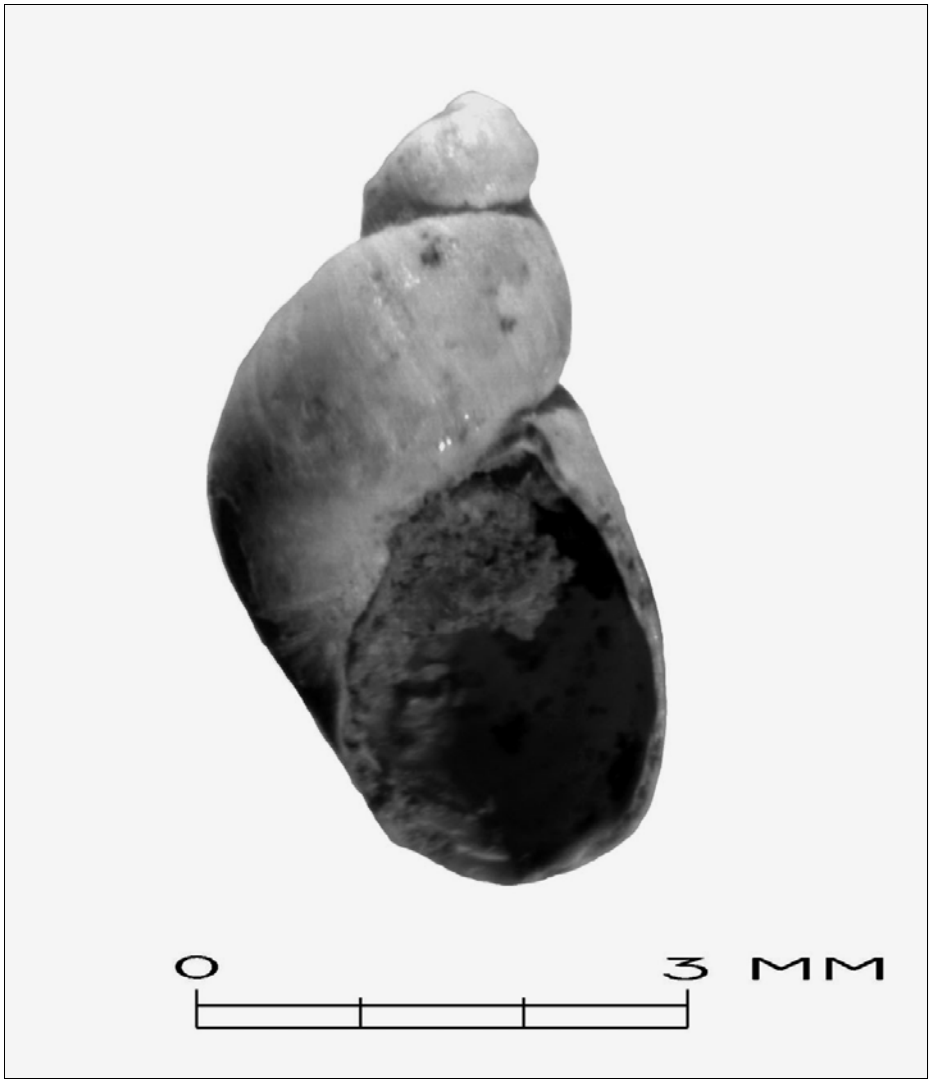


Figure 8.68. Lymnaeidae, cf. *Fossaria* sp. (?), Adaxial View. N112 E97 (93.14-92.75 m), Lot B-111.

Various species of *Fossaria* have been recovered from archeological or paleontological sites, such as the Aubrey, Wilson-Leonard, 41 WM 312, 41 CC 112, Skyline Shelter, the Sulphur Springs site, and the Hajny Mammoth site.

Physella virgata, PHYV

Matrix columns: 1 specimen
1/4-inch screen sample: 2 specimens
Body size: Small to medium sized, mean height 7.32 ± 1.65 mm for Texas populations (range, 1.8-14.9; Burnside 1998:Table 1, 63); 0.5-13.8 mm (McMahon 1975:Fig. 3)

This pulmonate species is listed as *Physa virgata* in the older literature. Although Burch and Tottenham (1980:184, 188, 190) recognize eight species of *Physella* in Texas, all with nearly identical shells, Fullington (1978b) recognizes only one living species, *P. virgata*. This genus exhibits extreme phenotypic plasticity in shell size and shape. Burnside (1998) carried out an extensive morphometric study of *Physella* shells in 66 samples from Texas and nearby areas of adjacent states, concluding all of the previously recognized species can be collapsed into a single highly variable species, which he suggests should be assigned the name *Physella heterostropha* by taxonomic priority rules (Burnside 1998:102). Shell length for all 66 samples was found to be normally distributed (Burnside 1998:Fig. 12). Based on crossbreeding experiments, Dillon and others (2005) recommend subsuming this species under *Physa acuta*, but for the present study, I will adhere to the recognized name *Physella virgata*.

A few examples of this taxon were also found at the Smith Creek Bridge site, and I refer the reader to the more extensive discussion there (Brown 2002:255). One of the Smith Creek specimens had a red-pigmented spire, but none of the Berger Bluff specimens have any pigmentation. One of the specimens from the 1/4-inch screen sample is a very small basal fragment (only2.9 mm high) from an embryonic or juvenile, tentatively identified as *Physella* (N109 E96, 92.35-92.30 m). The other (N111 E101, 92.55-92.50 m) is also fragmentary, with an estimated height of about 14.7 mm.

> This species has a very high heat tolerance and has been documented living in artificially heated water as high as 39.5° C (103.1° F; McMahon 1975:1173). It has also been found in cobble riffles in the cold, clear water of the Devil's River (Davis 1980). Neck (1986a:425) found it in a springfed stream near Kenyon Rockshelter and in playa lakes in the Panhandle on aquatic vegetation (Neck and Schramm 1992). According to Fullington, *Physella virgata* may be found in almost any kind of aquatic habitat and has a statewide distribution (Brown 2002:255).
>
> Physids have been collected from acidic bayous in East Texas to ephemeral pools in high canyons of the Guadalupe Mountains. *Physa*, like other pulmonate freshwater snails has the ability to aestivate during periods of drought. Because they can tolerate aquatic environmental extremes and due to their apparent genetic plasticity, shell form is extremely variable and, in Texas at least, reflects Texas edaphic features. In acidic, sandy-bottomed east Texas water, physid colonies are dwarfed. In the Central Texas limestone region, shell size and variability within populations is pronounced. Westward, even though most of the surface rocks and soils are basic pH, colonies are again dwarfed (Fullington 1978b:182).

Crowl and Schnell (1990:366) found that where crawdads are abundant, these snails are large in size but have low population densities; and conversely, in the absence of crawdads, the snails are small, but in dense populations. *Physella virgata* has been found at the Aubrey site, Rex Rodgers, the Richard Beene site, La Paloma Mammoth site (Neck 1981a), Wilson-Leonard site, Aquilla Lake, 41 WM 56, 41 WM 304, 41 WM 328 (Fullington and Fullington 1982b), 41 WM 312 (Voellinger and Gearhart 1987), the Perry site (Fullington 1987), Skyline Shelter, 41 CC 112, and the Mustang Branch site, as well as the Lehner and Murray Springs sites in Arizona (Bequaert and Miller 1973:202).

The few examples of *Physella* from the bench deposits are regarded as cosmopolitan eurytopic aquatic snails. These snails could be derived either from Coleto Creek or from a nearby spring run. Various species of *Physa* or *Physella* are often found in spring habitats (see Wilhm 1970; Varza and Covich 1995; Gaskin and Bass 2000).

Planorbella trivolvis (Fig. 8.69), PTRI

Matrix columns: 28 specimens
1/4-inch screen sample: 13 specimens
Body size: Large, maximum diameter 19.5-31.7 mm (in Canada, Clarke 1973:453-454); 13.4-20.5 mm (in Texas, Logsdon 1967:41)

Fullington (1978b:17) classifies these snails as *Helisoma trivolvis lenta*, but they are simply recognized here as *Planorbella trivolvis*. The following information is excerpted from the Smith Creek Bridge site report:

"*Planorbella trivolvis* is a common and widely distributed aquatic snail and is frequently found in stagnant, ponded water (Branson 1961b:62), although it also occurs in creeks and rivers (La Rocque 1968:503), and is

> most often found in shallow water one foot or less deep on ooze-covered bottoms, rocks covered with algae, and dead leaves and stems of plants. Occasionally *trivolvis* is found out of the water on wet vegetation (Leonard 1959:58-59).

In Texas, Fullington (1978b:206) reports

> It was very common in the shallow backwater areas of streams where green algae was [*sic*] abundant. However, it was also common in the shallow, protected coves of lakes where I found it crawling on mud, old cans, and on stems of emergent vegetation. *Physa virgata* usually was associated....

Logsdon (1967:41) found these in ponds, transient pools, creeks, and the Trinity River, on floating wood, submerged limbs and sticks, and on shallow, ooze-covered bottoms. *Planorbella trivolvis* is fairly resistant to drying of its habitat and can be found in ephemeral ponds and tanks that disappear in midsummer. Although in northern regions, it burrows to escape winter freezes, in Texas it probably burrows into bottom

mud to escape summer drying of water bodies (Cheatum 1934b:394). Gradual desiccation of oxbows or sloughs will concentrate these snails in the deepest part. Although in extremely dry conditions (relative humidity of only 12-14%), it can only survive two hours or less out of water, in more humid conditions (96-98% relative humidity), it can survive out of water about three weeks (Gallo, Fried and Holliday 1984). Cheatum (1934b:393) was able to keep eight out of 20 *P. trivolvis* alive for 68 days in mud that was artificially wetted at intervals (the 18 *H. anceps* in the experiment did not survive). In another experiment involving naturally damp mud, eight out of 15 survived 62 days. *P. trivolvis* specimens from the River Spur site had pronounced varices that I suspect may have been due to midsummer desiccation of the oxbow (Brown 2002:254).

Examples of this species are found in throughout the stratigraphic section in the bench deposits, in all strata. They are somewhat more abundant in strata 2A, 2B, and 2D/3. It should be noted that although Raymond Neck apparently classified all of the *Helisoma* from the matrix columns as *Helisoma trivolvis* (= *Planorbella trivolvis*), in cases where I have re-examined the same specimens, I would have classified them as *Helisoma anceps*. Specimens of *Planorbella trivolvis* from the 1/4-inch screen range from juveniles about 5.4 mm in diameter to adults as much as 18.9 mm in diameter. The mean diameter is 13.20 ± 4.62 mm. A couple of individuals have faintly developed varices, and one has two episodes of shell damage followed by repair. In the bench deposits, this species is regarded as a eurytopic, drought-resistant aquatic snail probably indicative of stagnant or slow-moving, likely turbid waters. It is perhaps the most common aquatic snail reported from Texas archeological sites. A list of examples may be found in the Smith Creek Bridge site report (Brown 2002:254-255) but will not be

repeated here. About three dozen were also found at the Pavo Real site (Brown 2003:271).

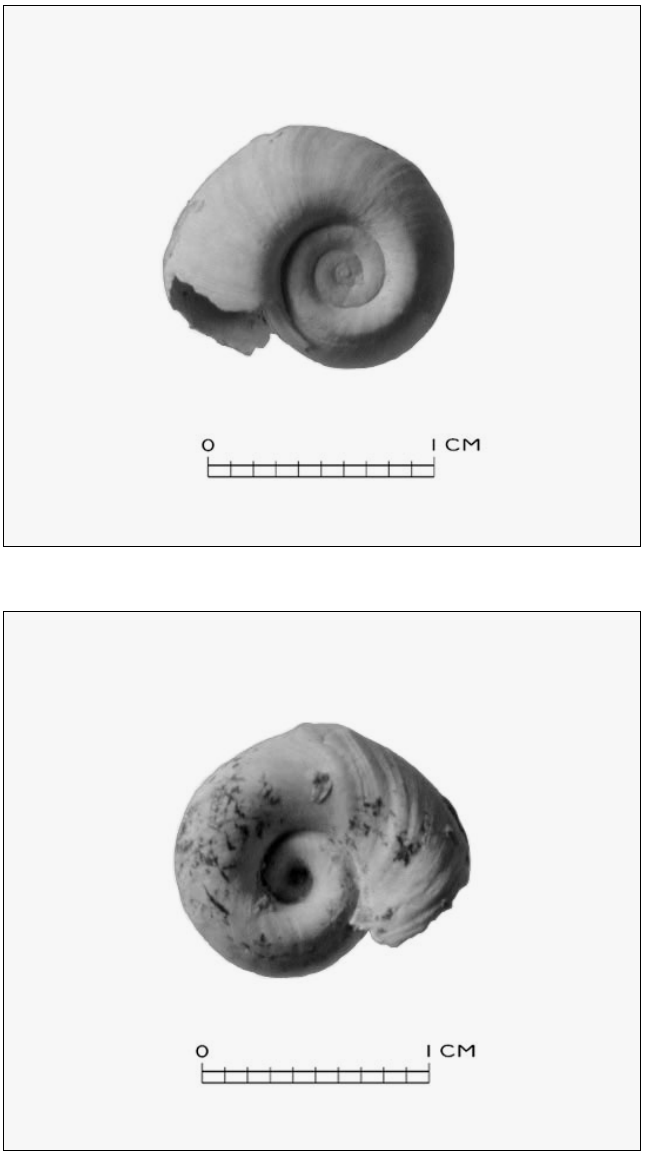


Figure 8.69. *Planorbella trivolvis*. *Top*, apical view; *bottom*, umbilical view. N112 E97 (93.14-92.75 m), Lot B-111, largest of three specimens in this lot.

Valvata tricarinata (Figs. 8.70-8.75), VALT

Matrix columns: 3 specimens
1/4-inch screen sample: 1 specimen
N109 E96 bulk matrix: 6 specimens
Body size: Microsnail, height 1.5-5.1 mm (mean about 3.34 mm; Clarke 1973:235)

This small but distinctive, turreted, operculate prosobranch snail is a species with northern affinities, extirpated in Texas now but a characteristic fossil in Pleistocene deposits in Texas and elsewhere. It occurs extensively in Canada, where its range extends above N 55° latitude, to Hudson Bay and beyond, with some occurrences almost to N 68° latitude, near the Beaufort Sea (Clarke 1973:238). In the eastern US, it extends from Virginia westward to the eastern part of the Great Plains (La Rocque 1968:Fig. 221). It is found in all the Great Lakes and occurs in Illinois, Wisconsin, Iowa (Bovbjerg, Dusil and Broer 1982), Montana (?), Washington, and North and South Dakota. According to Taylor (1960:48), the southernmost known occurrence is in Nebraska:

> A species found only in permanent lakes and rivers. In northern Nebraska this species was found in a spring-fed pond of temperature 15° C. The snails were crawling on aquatic plants, largely *Ceratophyllum*, *Elodea*, and algae, near the edge of the pond… *Valvata tricarinata* was found considerably south of its previously known range… Its existence at this locality is considered possible because of the insulating effect of the cool spring water. This northern species is probably able to live here because the pond is warmed little if at all during the summer hot spells. Other permanent ponds in Cherry County, apparently similar except that they lack spring sources, were examined without finding this species.

It should be noted that Wallen and Dunlap (1955:79) report finding *Valvata tricarinata* in Woodward County, Oklahoma, and Branson (1961b:38-39) apparently accepts this as a valid record for a living population. If so, this is probably the southernmost record for live populations (Woodward County is in western Oklahoma, just north of N 36° latitude). However, Neck (1982) doubts the existence of living

populations. According to Burch and Jung (1987:239), it also occurs in Arkansas. Branson (1967:299) also reports a single specimen in river drift from the mouth of the Colorado River in Matagorda County, but this is undoubtedly a redeposited fossil.

Regarding the species in Canada, Clarke (1973:237) says

> Of 80 *Valvata tricarinata* collections made during this survey, 30 are from large lakes, 4 from small lakes, 2 (only 1 specimen each) from permanent ponds, 6 from backwater areas of large subarctic rivers, 15 from rivers over 100 feet wide, 7 from rivers 50 to 100 feet wide, 8 from rivers 25 to 50 feet wide, 4 from permanent streams 10 to 25 feet wide, and 4 from subarctic muskeg. Bottom sediments were of all types, aquatic vegetation was present at nearly all localities and in lotic habitats current was moderate, slow or not discernible.

Clarke goes to add that the species was not found in small or temporary ponds. In Minnesota, Dawley (1947) found the species in small streams, large rivers, soft-water and medium-hard water lakes, hard-water prairie lakes, and river lakes, on shallow sandy beaches and on vegetation. Mackie and Flippance (1983:Table 1) found it waters with a pH range of 6.00-8.37. Horst and Costa (1971) studied the species in McCargo Lake, New York, and found it most abundant at a water depth of two meters and temperature of 24° C, which is probably unusually warm for the species. A more typical temperature range is probably at or below the 15° C temperature reported by Taylor. For comparison, the pre-impoundment aquatic ecology study of Coleto Creek measured water temperature at 17° in February to 30° in July (Murray, Jinnette and Moseley 1976:Table 1). The species is widespread and abundant in Alberta, mostly in hard water rivers and lakes (uncommonly in creeks and ponds) with a mean pH of 9.1 (range, 8.1-10.0; Prescott and Curteanu 2004:16).

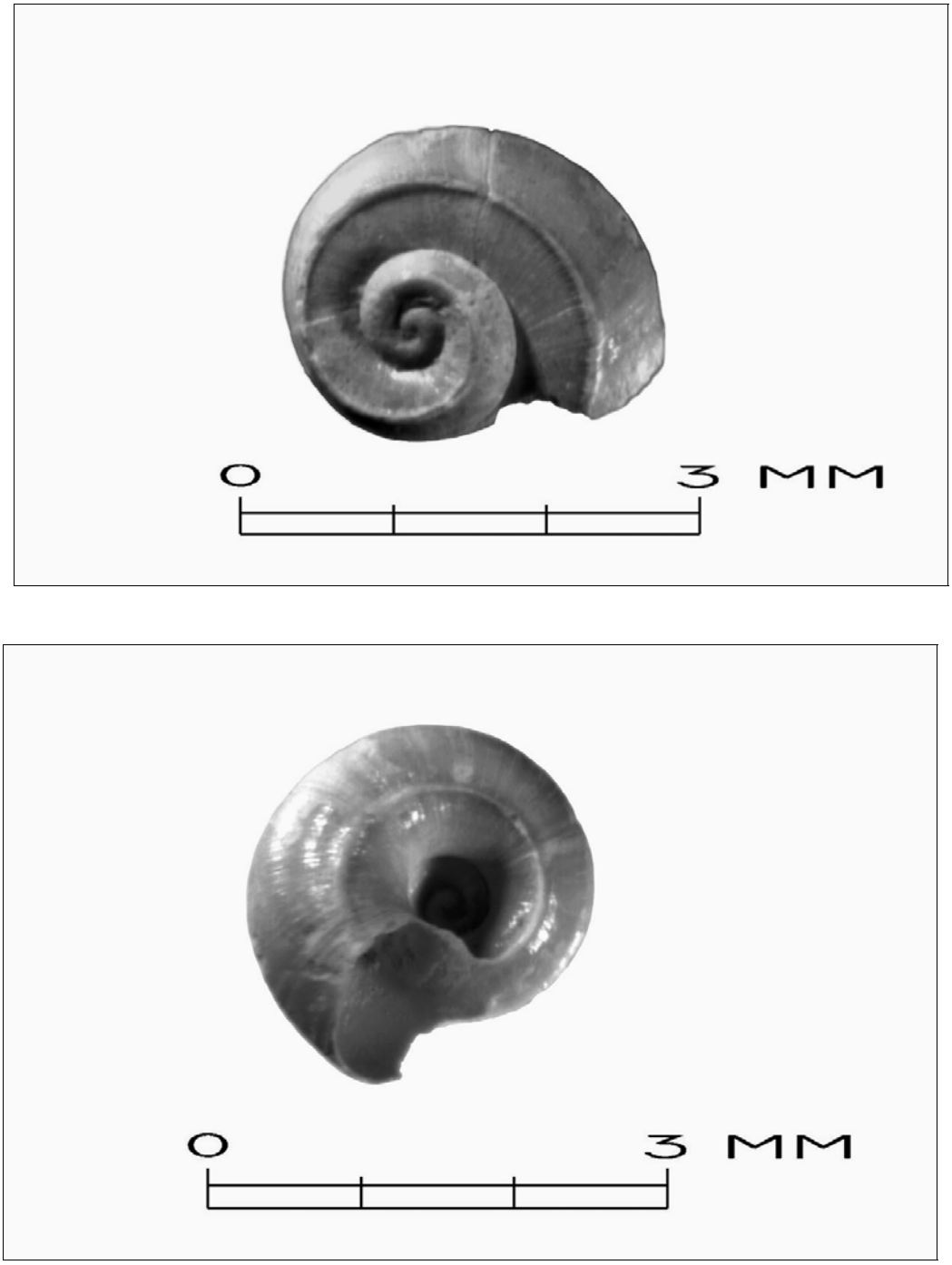


Figure 8.70. *Valvata tricarinata*. *Top*, apical view; bottom, umbilical view. N109 E96, bulk matrix, coarse fraction (92.70-92.65 m). Note three varices visible in top view.

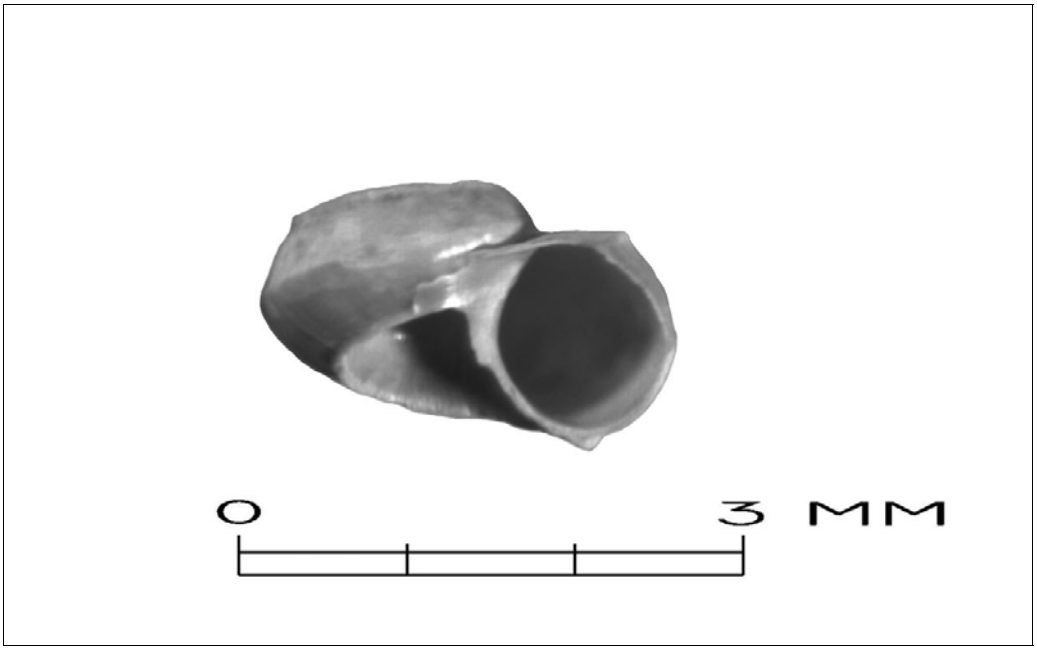


Figure 8.71. *Valvata tricarinata*, Adaxial View. Same specimen as shown in previous figure.

Valvata tricarinata is a common Pleistocene marker fossil in Texas and elsewhere. It occurs abundantly in the Carrollton Alluvium at the Aubrey site, somewhat less abundantly in the pond axis and pond margin (Neck 2001:Tables 7.1, 7.2, 7.3). At Lubbock Lake, it becomes extinct between Stratum 1, where it is present (11,100 RCYBP) and Stratum 2, where it is absent (10,500 RCYBP; Pierce 1987:Table 6.2). It is found at the Rex Rodgers and Snail Bed (41 BI 57) sites. It also occurs in the Clear Creek and Ben Franklin faunas (Cheatum and Allen 1963), the South Fish Creek and Gifford-Hill local faunas, Dallas County (Willimon 1972:Table 1). Hubricht (1962:1) reports large numbers of *Valvata tricarinata* from an undated locality on Palo Blanco Creek in Brooks County.

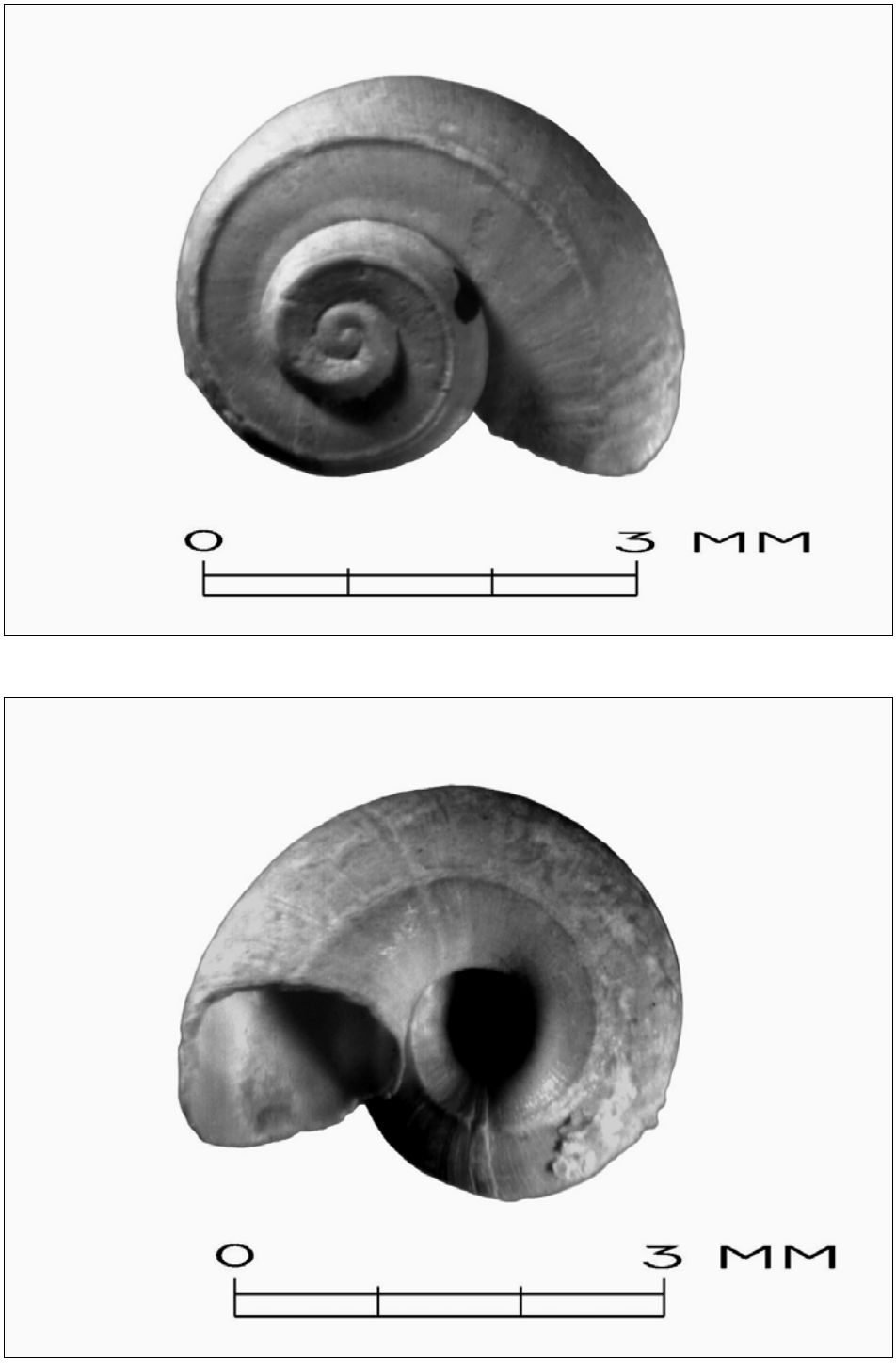


Figure 8.72. *Valvata tricarinata*. *Top*, apical view; *bottom*, umbilical view. N109 E96, bulk matrix, coarse fraction (92.55-92.50 m). Larger of two specimens in this lot.

Figure 8.73. *Valvata tricarinata*, Apical View. N109 E96, bulk matrix, coarse fraction (92.55-92.50 m). Smaller of two specimens in this lot.

Todd (2002:Table 1) reports one specimen (along with 8 specimens of *Cincinnatia integra*) from mid-Holocene context in a site at Brady. I suspect this specimen is redeposited. It occurs at paleontological localities associated with archeological site 41 CC 255 (along with *Cincinnatia integra* and *Elimia comalensis*), investigated during the All-American Pipeline Project. This site is located on Kickapoo Creek in western Concho County. Fullington (1978b:82) reports fossil records from the counties of Armstrong, Delta, Denton, Hardeman, Motley, Randall, and Swisher. The species is found at the Plainview site (Neck 1995b:Table 25), but has not been reported from the Lake Theo, Richard Beene or Wilson-Leonard sites, nor from any of the Llano Estacado localities studied by Drake (1975).

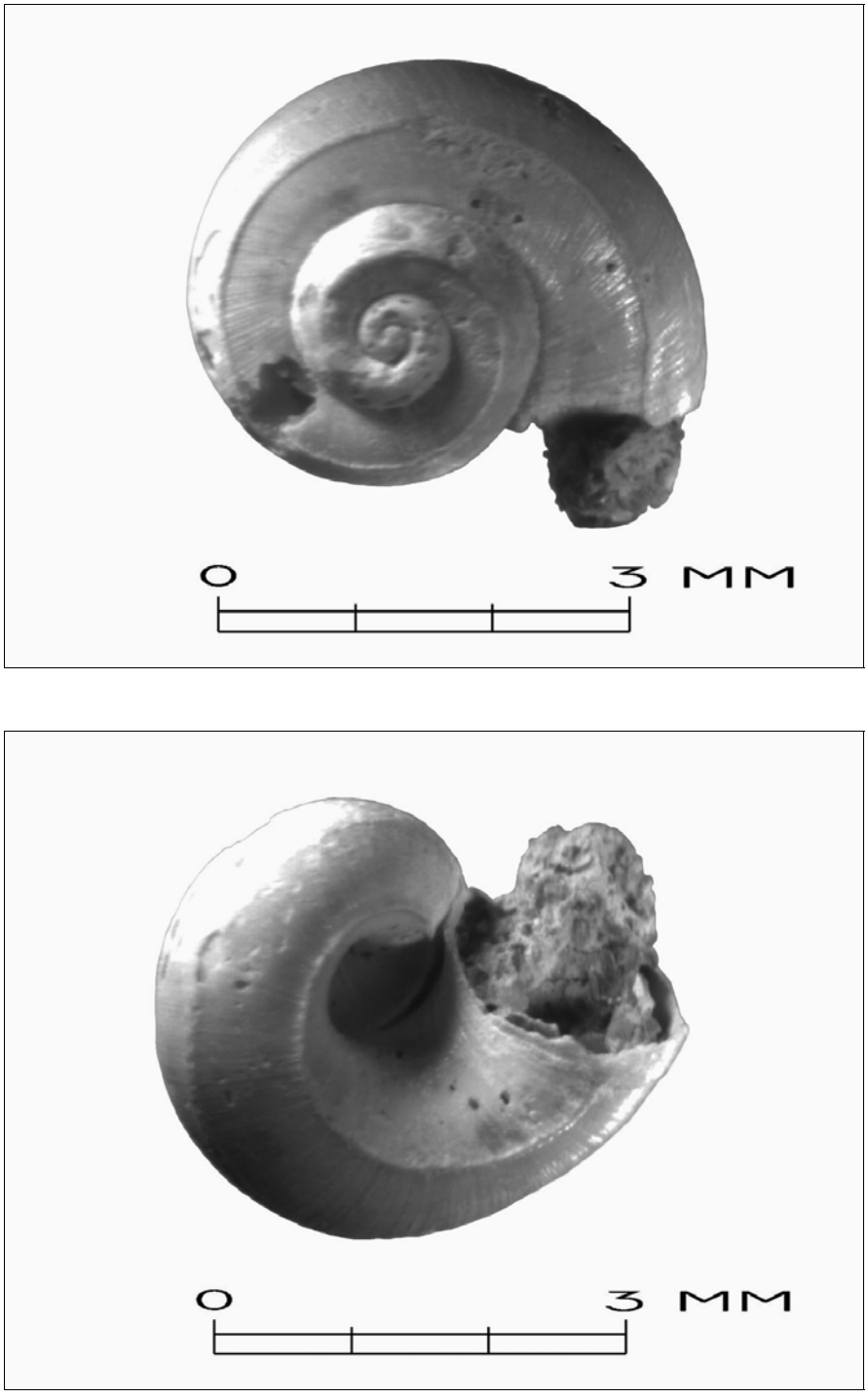


Figure 8.74. *Valvata tricarinata*. *Top*, apical view; *bottom*, umbilical view. N 109 E96, bulk matrix, coarse fraction (92.35-92.30 m). Larger of two specimens.

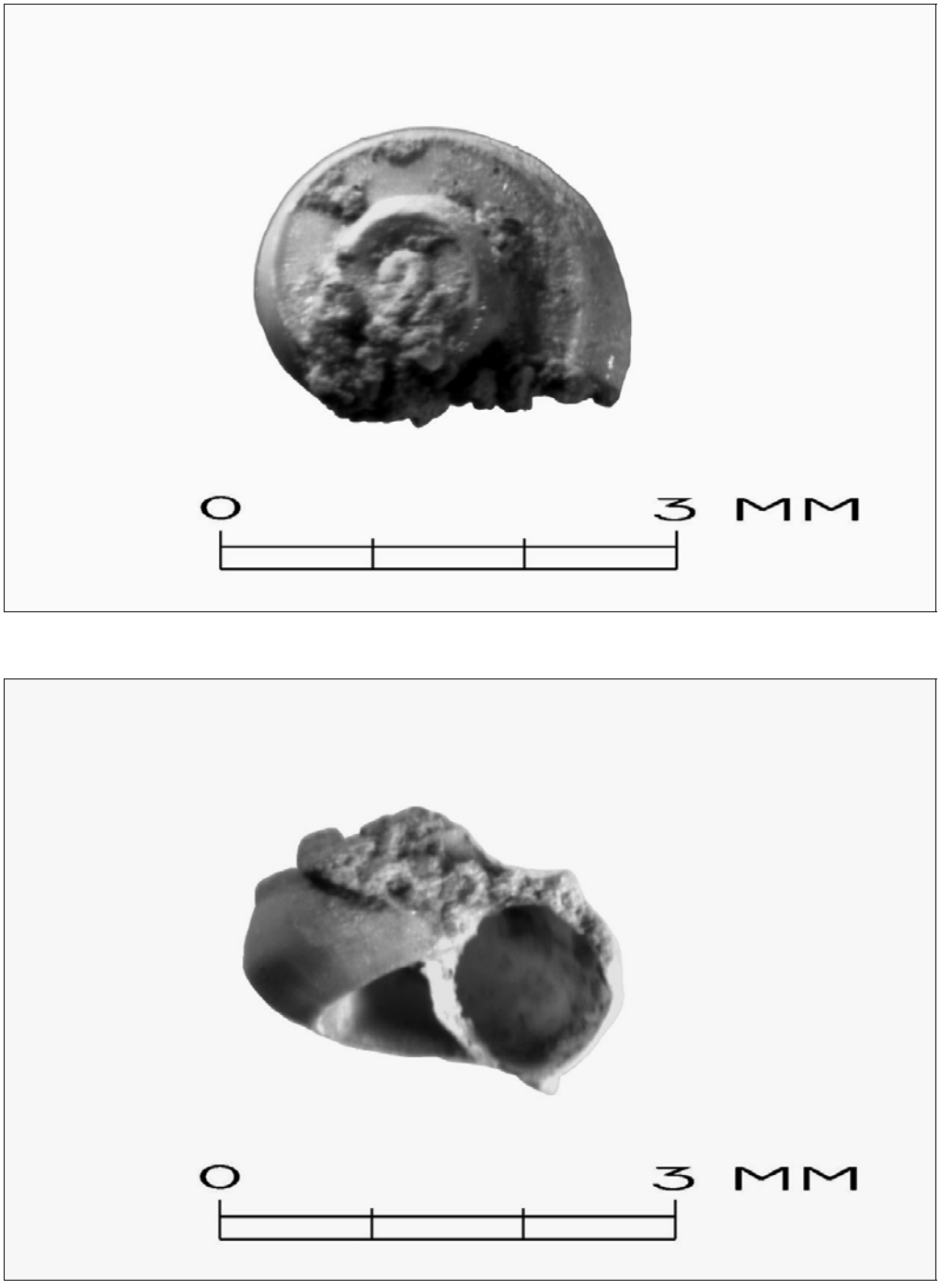


Figure 8.75. *Valvata tricarinata*. *Top*, apical view; *bottom*, adaxial view. N112 E97 (92.25-92.20 m), Lot B-97.

Beyond Texas, it occurs at the Domebo site (Cheatum and Allen 1966), the Burnham site (Theler 2003a, 2003b), the Butler Spring Sloth Locality in Kansas (Devore 1975), the Dows Local Biota of Iowa (Hudak 1984), the Perry Mastodon site in Illinois (Adams and Fraunfelter 1974), the Nonconnah Creek Mastodon site, Tennessee (Brister, Armon and Dye 1982), various Pleistocene localities in North Dakota (Clayton 1961; Tuthill 1961), the Berends and Doby Springs local faunas of Oklahoma and the Mount Scott local fauna of Kansas (Miller 1966). See La Rocque (1968:367) for additional fossil localities.

From the distributional evidence, it is clear that *Valvata tricarinata* extended far to the south of its present geographic range during the Pleistocene, the southernmost reported locality being the one near Falfurrias, in Brooks County, reported by Hubricht. although the species is often found in abundance in deep lakes today (including all of the Great Lakes), it likely inhabited cold springs and springfed creeks and ponds at the southern edge of its range during the Pleistocene and earliest Holocene. Depending on the near-constant temperature groundwater sources at these sites, it evidently experienced a major northward range retraction (to about N36-37° or beyond) as groundwater sources diminished with the onset of the Holocene.

These are very small snails, easily overlooked if fine screening is not done. Several specimens were discovered while picking bulk matrix samples from N109 E96. These range from a probable juvenile 1.6 mm in diameter and 1.0 mm high, to an adult 3.9 mm in diameter and 2.8 mm high. Because there are many levels in this unit that have not yet been picked, there are probably additional specimens yet to be discovered. Table

8.19 shows the provenience of the known specimens of *Valvata tricarinata*. Examples were found in strata 1, 2A, 2B, and 2D.

In the bench deposits, this species is regarded as a Pleistocene marker fossil, most likely a cold spring inhabitant.

Table 8.19. Provenience of *Valvata tricarinata* Specimens.

	Stratum	No. of specimens	Height (mm)	Diameter (mm)
N109 E103 Matrix Column				
92.10-92.05	2A	1	*	
N110 E102 Matrix Column				
92.05-92.00	2A	1	*	
91.75-91.70	1	1	*	
N112 E99, 1/4-inch Screen Sample				
92.25-92.20	2A	1	2.0	2.3
N109 E96 Bulk Matrix				
92.70-92.65	$2D_2$	1	1.5	2.2
92.55-92.50	$2D_1$	3	2.4	3.4
			1.6	2.8**
			1.7	2.4
92.35-92.30	2B	2	2.8	3.9
			1.0	1.6***

* unavailable for measurement; sent to SMU as voucher specimen by Neck
** probable juvenile
*** probable juvenile with chipped aperture

INTERPRETATION OF THE QUARTER-INCH SCREEN SAMPLE

Tables 8.20 through 8.25 record the snails recovered on the 1/4-inch screen (fortuitously recovered microsnails, most of them derived from sediment lodged in the apertures of larger species, are also included). Figures 8.76 through 8.78 show the proportional representation of large and medium-bodied genera in the 1/4-inch screen sample from all units combined except Unit 2 and N113 E98. To compile these simplified diagrams, microsnails were disregarded, all *Rabdotus* age classes were combined, and all *Mesodon* and all *Praticolella* categories were combined. Except for two cases, excavation levels that included more than one stratum were grouped with the stratum having the greatest representation in the level. In two cases, levels evenly split between strata were simply omitted from the counts.

A major issue raised in Chapter 4 was whether biological remains would sort out consistently into assemblages that correspond to the muddy (stratum 2A, 2C, and 3) and sandy (stratum 1, 2B, 2D) units visible in the bench deposits, or instead show long-term trends that crosscut strata. For the large and medium-bodied snail, the major trends seem to be ones that crosscut strata. The diagrams show that from the base of the section upward,

1) *Anguispira strongylodes* becomes less abundant;
2) *Oligyra orbiculata* becomes more abundant;
3) *Rabdotus* sp., *Polygyra texasiana*, and *Mesomphix friabilis* remain the next most abundant genera; these three simply shift relative ranks from stratum 2A through 2D;

4) *Mesodon* species, *Euchemotrema leai*, *Praticolella pachyloma*, and aquatic genera remain minor elements throughout; *Praticolella* is well represented only in stratum 2A.

These trends probably represent long-term drying of the habitat. Both *Anguispira* and *Oligyra* have rather durable shells, so it is unlikely these trends are taphonomic in nature. *Anguispira* is a woodland snail, and its decline over time may be due to reduction in riparian tree canopy, although *Mesomphix*, also a woodland snail (and a frequent associate of *Anguispira*) does not show the same decline. The increase in *Oligyra* over time likely signals increasingly stressful and drought-prone habitats or climates, since this genus is typically hardy and very resistant to drought. It is also advisable to keep in mind that *Oligyra* is small enough that many of the shells will pass through a 1/4-inch screen, and this has undoubtedly affected the counts. The apparent low representation of some genera (such as *Mesodon* and *Praticolella*) may be due in large part to shell fragility.

Of the major genera represented, *Anguispira*, *Mesomphix*, *Mesodon*, and *Euchemotrema* are typically woodland inhabitants and probably indicate the presence of riparian deciduous woodland. *Oligyra* and *Rabdotus* are generally found in more open areas, ranging from grassland to chaparral to parkland. Presumably these snails are derived either from more open areas of the floodplain or from open slopes adjacent to the floodplain.

Table 8.20. Snails Recovered From the Quarter-Inch Screen in N109 E103.

N109 E103	93.14-92.90	92.90-92.85	92.85-92.80	92.80-92.75	92.75-92.75	92.70-92.65	92.65-92.60	92.60-92.55	92.55-92.50	92.50-92.45	92.45-92.40	92.40-92.35	92.35-92.30	92.30-92.25
Terrestrial, large/medium														
Anguispira strongylodes	48	24	19	13	12	13	17	9	1	6	7	2	1	1
Euchemotrema leai adults	4			1	1	3	2							1
Mesodon cf. *M. roemeri*														
Mesodon cf. *M. thyroidus*	2	1												
Mesodon sp., fragmentary	6	5	5	1	2	3	1	1		1				
Mesomphix friabilis	82	42	44	21	16	10	5	2	1	6	6	3	1	1
Oligyra orbiculata adults	323	145	141	80	97	64	52	36		9	13	6	7	6
Polygyra texasiana adults	87	47	17	12	24	18	12	5	1	4	3	2	1	1
Polygyra sp., fragmentary	32	5	5	6	5	5	4	2		1	1	1		1
Praticolella cf. *P. pachyloma*	1	1			2	1								
Praticolella sp., fragmentary	1	1	6	1	1			4					1	
Rabdotus sp. adults	26	14	5	10	5	5	5	3	2	2	3	2		7
Rabdotus sp. juveniles	21	22	12	16	16	6	6	3		3	4		1	1
Rabdotus sp., age class indet.	13		3	2		1		3						
Unlipped shells	2													
Unidentified, terrestrial	10		3											
Aquatic, large/medium														
Helisoma anceps						1								
Physella virgata														
Planorbella trivolvis						1								
Planorbidae, unidentified	1				2							1		
Miscellaneous terrestrial														
Opercula from *O. orbiculata*	31	20	20	7	4	9	6	6		1	1	1		
Terrestrial, large/medium	658	307	260	163	181	129	104	68	5	32	37	16	12	19
Aquatic, large/medium	1	0	0	0	2	2	0	0	0	0	0	1	0	0
TOTAL:	659	307	260	163	183	131	104	68	5	32	37	17	12	19

(continued on next page)

(Table 8.20, continued from previous page)

N109 E103	92.25-92.20	92.20-92.15	92.15-92.10	92.10-92.05	92.05-92.00	92.00-91.95	91.95-91.90	**Row totals**	**Class totals**
Terrestrial, large/medium									**2097**
Anguispira strongylodes	5	5	9	3	4	2		201	
Euchemotrema leai adults		1	2					15	
Mesodon cf. *M. roemeri*								0	
Mesodon cf. *M. thyroidus*								3	
Mesodon sp., fragmentary			1					26	
Mesomphix friabilis	2	2	1	2	1			248	
Oligyra orbiculata adults	3	5	24	3	4	2		1020	
Polygyra texasiana adults	1	1						236	
Polygyra sp., fragmentary	1		1		1			71	
Praticolella cf. *P. pachyloma*								5	
Praticolella sp., fragmentary			1	1		1		18	
Rabdotus sp. adults	1	3						93	
Rabdotus sp. juveniles	2	4	2					119	
Rabdotus sp., age class indet.			4		1			27	
Unlipped shells								2	
Unidentified, terrestrial								13	
Aquatic, large/medium									**11**
Helisoma anceps	1	1	2		1			6	
Physella virgata								0	
Planorbella trivolvis								1	
Planorbidae, unidentified								4	
Miscellaneous terrestrial									
Opercula from *O. orbiculata*	1		2						109
Terrestrial, large/medium	15	21	45	9	11	5	0		
Aquatic, large/medium	1	1	2	0	1	0	0		
TOTAL:	16	22	47	9	12	5	0		

(continued on next page)

(Table 8.20, continued from previous page)

N109 E103	93.14-92.90	92.90-92.85	92.85-92.80	92.80-92.75	92.75-92.75	92.70-92.65	92.65-92.60	92.60-92.55	92.55-92.50	92.50-92.45	92.45-92.40	92.40-92.35	92.35-92.30	92.30-92.25
Terrestrial microsnails														
Carychium mexicanum														
Catinella vermeta				1										
Gastrocopta contracta	3	3		1			1							
Gastrocopta pellucida														
Gastrocopta pentodon (?)														
Gastrocopta cf. *G. procera*			1											
Gastrocopta sp.		2												
cf. *Glyphyalinia roemeri*			1											
Glyphyalinia umbilicata	6	1		2		3		1						
Helicodiscus singleyanus	7	11	3	1	1	2	1			1		1		
cf. *Pupisoma dioscoricola*				1										
Pupoides albilabris	1						1							
Strobilops texasiana														
Zonitoides arboreus						1								
Zonitidae, cf. *Nesovitrea* sp.														
Unident. terrestrial microsnails	2			1										
Aquatic microsnails														
Cincinnatia cincinnatiensis		1												
Gyraulus parvus							1							
Lymnaeidae, cf. *Fossaria* sp.														
Planorbidae, unidentified														
Pomatiopsis lapidaria														
Valvata tricarinata														
Miscellaneous aquatic														
Sphaeriid clams														
Pisidium sp.														

(continued on next page)

(Table 8.20, continued from previous page)

N109 E103	92.25-92.20	92.20-92.15	92.15-92.10	92.10-92.05	92.05-92.00	92.00-91.95	91.95-91.90	**Row totals**	**Class totals**
Terrestrial microsnails									**63**
Carychium mexicanum								0	
Catinella vermeta								1	
Gastrocopta contracta				1				9	
Gastrocopta pellucida								0	
Gastrocopta pentodon (?)								0	
Gastrocopta cf. *G. procera*								1	
Gastrocopta sp.								2	
cf. *Glyphyalinia roemeri*								1	
Glyphyalinia umbilicata								13	
Helicodiscus singleyanus	1							29	
cf. *Pupisoma dioscoricola*								1	
Pupoides albilabris								2	
Strobilops texasiana								0	
Zonitoides arboreus								1	
Zonitidae, cf. *Nesovitrea* sp.								0	
Unident. terrestrial microsnails								3	
Aquatic microsnails									**4**
Cincinnatia cincinnatiensis			1					2	
Gyraulus parvus						1		2	
Lymnaeidae, cf. *Fossaria* sp.								0	
Planorbidae, unidentified								0	
Pomatiopsis lapidaria								0	
Valvata tricarinata								0	
Miscellaneous aquatic									**2**
Sphaeriid clams		1						1	
Pisidium sp.					1			1	

(End of Table 8.20)

Table 8.21. Snails Recovered From the Quarter-Inch Screen in N110 E102.

N110 E102	93.08-92.90	92.90-92.80	92.80-92.75	92.75-92.70	92.70-92.65	92.65-92.60	92.60-92.55	92.55-92.50	92.50-92.45	92.45-92.40	92.40-92.35	92.35-92.30	92.30-92.25	92.25-92.20
Terrestrial, large/medium														
Anguispira strongylodes	14	9	9		6	19	8	4	5	4	1	2	2	1
Euchemotrema leai adults							1							
Mesodon cf. *M. roemeri*														
Mesodon cf. *M. thyroidus*	3		1	1			1							
Mesodon sp., fragmentary		3	1			1		1		1		1		
Mesomphix friabilis	22	28	21	3	3	8	1	3	6	4	2	1	2	1
Oligyra orbiculata adults	42	44	116	42	29	29	13	3	5		5		2	
Polygyra texasiana adults	16	10	22	8	7	18	5		2	2	3			2
Polygyra sp., fragmentary	1	2	4			6								1
Praticolella cf. *P. pachyloma*					2									
Praticolella sp., fragmentary			2											
Rabdotus sp. adults	7	12	17	2	4	6	1		3		2	1		
Rabdotus sp. juveniles	4	2	14	4	8	3	1		1		1			
Rabdotus sp., age class indet.														1
Unlipped shells			1											
Unidentified, terrestrial														
Aquatic, large/medium														
Helisoma anceps														
Physella virgata														
Planorbella trivolvis						1								
Planorbidae, unidentified			1											
Miscellaneous terrestrial														
Opercula from *O. orbiculata*	3	7	13	7		4	2		1					
Terrestrial, large/medium	109	110	208	60	59	90	31	11	22	11	14	5	6	6
Aquatic, large/medium	0	0	1	0	0	1	0	0	0	0	0	0	0	0
TOTAL:	109	110	209	60	59	91	31	11	22	11	14	5	6	6

(continued on next page)

(Table 8.21, continued from previous page)

N110 E102	92.20-92.15	92.15-92.10	92.10-92.05	92.05-92.00	92.00-91.95	91.95-91.90	91.90-91.85	91.85-91.80	91.80-91.75	91.75-91.70	91.70-91.65	91.65-91.60	91.60-91.55	**Row totals**	**Class totals**
Terrestrial, large/medium															**812**
Anguispira strongylodes	6	11	2			1								104	
Euchemotrema leai adults														1	
Mesodon cf. *M. roemeri*														0	
Mesodon cf. *M. thyroidus*														6	
Mesodon sp., fragmentary		1												9	
Mesomphix friabilis	4	1		1										111	
Oligyra orbiculata adults	10	11		2		1								354	
Polygyra texasiana adults	2	3		2	1									103	
Polygyra sp., fragmentary														14	
Praticolella cf. *P. pachyloma*	1													3	
Praticolella sp., fragmentary	4	3												9	
Rabdotus sp. adults	1	1												57	
Rabdotus sp. juveniles	1													39	
Rabdotus sp., age class indet.														1	
Unlipped shells														1	
Unidentified, terrestrial														0	
Aquatic, large/medium															**4**
Helisoma anceps														0	
Physella virgata														0	
Planorbella trivolvis		2												3	
Planorbidae, unidentified														1	
Miscellaneous terrestrial															
Opercula from *O. orbiculata*	1	1													39
Terrestrial, large/medium	29	31	2	5	1	2	0	0	0	0	0	0	0		
Aquatic, large/medium	0	2	0	0	0	0	0	0	0	0	0	0	0		
TOTAL:	29	33	2	5	1	2	0	0	0	0	0	0	0		

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(Table 8.21, continued from previous page)

N110 E102	93.08-92.90	92.90-92.80	92.80-92.75	92.75-92.70	92.70-92.65	92.65-92.60	92.60-92.55	92.55-92.50	92.50-92.45	92.45-92.40	92.40-92.35	92.35-92.30	92.30-92.25	92.25-92.20
Terrestrial microsnails														
Carychium mexicanum														
Catinella vermeta														
Gastrocopta contracta						1								
Gastrocopta pellucida														
Gastrocopta pentodon (?)														
Gastrocopta cf. *G. procera*														
Gastrocopta sp.														
cf. *Glyphyalinia roemeri*														
Glyphyalinia umbilicata		2	2		1	2	5							
Helicodiscus singleyanus			1	1	1	2		1		1				
cf. *Pupisoma dioscoricola*														
Pupoides albilabris														
Strobilops texasiana														
Zonitoides arboreus														
Zonitidae, cf. *Nesovitrea* sp.														
Unident. terrestrial microsnails			1											
Aquatic microsnails														
Cincinnatia cincinnatiensis														
Gyraulus parvus									1		1			
Lymnaeidae, cf. *Fossaria* sp.														
Planorbidae, unidentified														
Pomatiopsis lapidaria														
Valvata tricarinata														
Miscellaneous aquatic														
Sphaeriid clams														

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(Table 8.21, continued from previous page)

N110 E102	92.20-92.15	92.15-92.10	92.10-92.05	92.05-92.00	92.00-91.95	91.95-91.90	91.90-91.85	91.85-91.80	91.80-91.75	91.75-91.70	91.70-91.65	91.65-91.60	91.60-91.55	**Row totals**	**Class totals**
Terrestrial microsnails															**24**
Carychium mexicanum														0	
Catinella vermeta														0	
Gastrocopta contracta														1	
Gastrocopta pellucida														0	
Gastrocopta pentodon (?)														0	
Gastrocopta cf. *G. procera*														0	
Gastrocopta sp.														0	
cf. *Glyphyalinia roemeri*														0	
Glyphyalinia umbilicata	1													13	
Helicodiscus singleyanus	1													8	
cf. *Pupisoma dioscoricola*														0	
Pupoides albilabris														0	
Strobilops texasiana		1												1	
Zonitoides arboreus														0	
Zonitidae, cf. *Nesovitrea* sp.														0	
Unident. terrestrial microsnails														1	
Aquatic microsnails															**2**
Cincinnatia cincinnatiensis														0	
Gyraulus parvus														2	
Lymnaeidae, cf. *Fossaria* sp.														0	
Planorbidae, unidentified														0	
Pomatiopsis lapidaria														0	
Valvata tricarinata														0	
Miscellaneous aquatic															**1**
Sphaeriid clams				1										1	

(End of Table 8.21)

Table 8.22. Snails Recovered From the Quarter-Inch Screen in N111 E101.

N111 E101	92.89-92.80	92.80-92.70	92.70-92.65	92.65-92.60	92.60-92.55	92.55-92.50	92.50-92.45	92.45-92.40	92.40-92.35	92.35-92.30	92.30-92.25	92.25-92.20	92.20-92.15	92.15-92.10
Terrestrial, large/medium														
Anguispira strongylodes		11	11	24	15	23	2	4	3	5	2	4	2	8
Euchemotrema leai adults	1	2				2	1							
Mesodon cf. *M. roemeri*		2												
Mesodon cf. *M. thyroidus*														
Mesodon sp., fragmentary														
Mesomphix friabilis	4	17	9	7	3	10	1		1	1	1			1
Oligyra orbiculata adults	18	138	26	66	22	21	3	2	1	6	3	2	4	6
Polygyra texasiana adults	5	26	8	30	14	11	2	1		4	1	3	2	
Polygyra sp., fragmentary	2							1		1				1
Praticolella cf. *P. pachyloma*	2	2	1			1								
Praticolella sp., fragmentary	1			1	1	2		1						
Rabdotus sp. adults	3	18	4	6	4	3	1			1	1			
Rabdotus sp. juveniles	4	23	3	4		1				1				
Rabdotus sp., age class indet.														
Unlipped shells		6				1								
Unidentified, terrestrial		1					1							
Aquatic, large/medium														
Helisoma anceps		1		1		1								
Physella virgata						1								
Planorbella trivolvis														
Planorbidae, unident. large/med.				1										1
Miscellaneous terrestrial														
Opercula from *O. orbiculata*	4	26	4	14	6	3				1	1			1
Terrestrial, large/medium	40	246	62	138	59	75	11	9	5	19	8	9	8	16
Aquatic, large/medium	0	1	0	2	0	2	0	0	0	0	0	0	0	1
TOTAL:	40	247	62	140	59	77	11	9	5	19	8	9	8	17

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(Table 8.22, continued from previous page)

N111 E101	92.10-92.05	92.05-92.00	92.00-91.95	91.95-91.90	**Row totals**	**Class totals**
Terrestrial, large/medium						**707**
Anguispira strongylodes	1				115	
Euchemotrema leai adults					6	
Mesodon cf. *M. roemeri*					2	
Mesodon cf. *M. thyroidus*					0	
Mesodon sp., fragmentary					0	
Mesomphix friabilis					55	
Oligyra orbiculata adults	1				319	
Polygyra texasiana adults					107	
Polygyra sp., fragmentary					5	
Praticolella cf. *P. pachyloma*					6	
Praticolella sp., fragmentary					6	
Rabdotus sp. adults					41	
Rabdotus sp. juveniles					36	
Rabdotus sp., age class indet.					0	
Unlipped shells					7	
Unidentified, terrestrial					2	
Aquatic, large/medium						**6**
Helisoma anceps					3	
Physella virgata					1	
Planorbella trivolvis					0	
Planorbidae, unidentified large/med.					2	
Miscellaneous terrestrial						
Opercula from *O. orbiculata*						60
Terrestrial, large/medium	2	0	0	0		
Aquatic, large/medium	0	0	0	0		
TOTAL:	2	0	0	0		

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(Table 8.22, continued from previous page)

N111 E101	92.89-92.80	92.80-92.70	92.70-92.65	92.65-92.60	92.60-92.55	92.55-92.50	92.50-92.45	92.45-92.40	92.40-92.35	92.35-92.30	92.30-92.25	92.25-92.20	92.20-92.15	92.15-92.10
Terrestrial microsnails														
Carychium mexicanum			1											
Catinella vermeta														
Gastrocopta contracta				1										
Gastrocopta pellucida														
Gastrocopta pentodon (?)														
Gastrocopta cf. *G. procera*														
Gastrocopta sp.													1	
cf. *Glyphyalinia roemeri*														
Glyphyalinia umbilicata		3	2	5		1	1	2						
Helicodiscus singleyanus		6	2		1									
cf. *Pupisoma dioscoricola*														
Pupoides albilabris														
Strobilops texasiana														2
Zonitoides arboreus														
Zonitidae, cf. *Nesovitrea* sp.														
Unident. terrestrial microsnails			1											
Aquatic microsnails														
Cincinnatia cincinnatiensis				1										
Gyraulus parvus			1											
Lymnaeidae, cf. *Fossaria* sp.														
Planorbidae, unidentified														
Pomatiopsis lapidaria														
Valvata tricarinata														
Miscellaneous aquatic														
Sphaeriid clams														

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(Table 8.22, continued from previous page)

N111 E101	92.10-92.05	92.05-92.00	92.00-91.95	91.95-91.90	**Row totals**	**Class totals**
Terrestrial microsnails						**30**
Carychium mexicanum					1	
Catinella vermeta					0	
Gastrocopta contracta					1	
Gastrocopta pellucida					0	
Gastrocopta pentodon (?)					0	
Gastrocopta cf. *G. procera*					0	
Gastrocopta sp.					1	
cf. *Glyphyalinia roemeri*					0	
Glyphyalinia umbilicata					14	
Helicodiscus singleyanus		1			10	
cf. *Pupisoma dioscoricola*					0	
Pupoides albilabris					0	
Strobilops texasiana					2	
Zonitoides arboreus					0	
Zonitidae, cf. *Nesovitrea* sp.					0	
Unident. terrestrial microsnails					1	
Aquatic microsnails						**2**
Cincinnatia cincinnatiensis					1	
Gyraulus parvus					1	
Lymnaeidae, cf. *Fossaria* sp.					0	
Planorbidae, unidentified					0	
Pomatiopsis lapidaria					0	
Valvata tricarinata					0	
Miscellaneous aquatic						**0**
Sphaeriid clams					0	

(End of Table 8.22)

Table 8.23. Snails Recovered From the Quarter-Inch Screen in N112 E99.

N112 E99	92.89-92.60	92.60-92.55	92.55-92.50	92.50-92.45	92.45-92.40	92.40-92.35	92.35-92.30	92.30-92.25	92.25-92.20	92.20-92.15	92.15-92.10	92.10-92.05
Terrestrial, large/medium												
Anguispira strongylodes	33	7	4	8	1	1		3	7	3	6	1
Euchemotrema leai adults			1									
Mesodon cf. *M. roemeri*												
Mesodon cf. *M. thyroidus*												
Mesodon sp., fragmentary	2	1										
Mesomphix friabilis	20	8	1	2	3	1	1	1		1		
Oligyra orbiculata adults	58	5	13	5	3				1	2		
Polygyra texasiana adults	12	1	1	2				1	1			
Polygyra sp., fragmentary	5			2		1	1					
Praticolella cf. *P. pachyloma*												
Praticolella sp., fragmentary	2						1					
Rabdotus sp. adults	24	2	3	1	4			1		3		
Rabdotus sp. juveniles	10	1	4				1					
Rabdotus sp., age class indet.	4	2	1						1			
Unlipped shells												
Unidentified, terrestrial										1		
Aquatic, large/medium												
Helisoma anceps												
Physella virgata												
Planorbella trivolvis	2											
Planorbidae, unidentified	1											
Miscellaneous terrestrial												
Opercula from *O. orbiculata*	11		1								1	
Terrestrial, large/medium	170	27	28	20	11	3	4	6	10	10	6	1
Aquatic, large/medium	3	0	0	0	0	0	0	0	0	0	0	0
TOTAL:	173	27	28	20	11	3	4	6	10	10	6	1

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(Table 8.23, continued from previous page)

N112 E99	92.05-92.00	92.00-91.95	91.95-91.90	**Row totals**	**Class totals**
Terrestrial, large/medium					**296**
Anguispira strongylodes				74	
Euchemotrema leai adults				1	
Mesodon cf. *M. roemeri*				0	
Mesodon cf. *M. thyroidus*				0	
Mesodon sp., fragmentary				3	
Mesomphix friabilis				38	
Oligyra orbiculata adults				87	
Polygyra texasiana adults				18	
Polygyra sp., fragmentary				9	
Praticolella cf. *P. pachyloma*				0	
Praticolella sp., fragmentary				3	
Rabdotus sp. adults				38	
Rabdotus sp. juveniles				16	
Rabdotus sp., age class indet.				8	
Unlipped shells				0	
Unidentified, terrestrial				1	
Aquatic, large/medium					**3**
Helisoma anceps				0	
Physella virgata				0	
Planorbella trivolvis				2	
Planorbidae, unidentified				1	
Miscellaneous terrestrial					
Opercula from *O. orbiculata*					13
Terrestrial, large/medium	0	0	0		
Aquatic, large/medium	0	0	0		
TOTAL:	0	0	0		

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(Table 8.23, continued from previous page)

N112 E99	92.89-92.60	92.60-92.55	92.55-92.50	92.50-92.45	92.45-92.40	92.40-92.35	92.35-92.30	92.30-92.25	92.25-92.20	92.20-92.15	92.15-92.10	92.10-92.05
Terrestrial microsnails												
Carychium mexicanum												
Catinella vermeta		1										
Gastrocopta contracta												
Gastrocopta pellucida												
Gastrocopta pentodon (?)												
Gastrocopta cf. *G. procera*												
Gastrocopta sp.			1									
cf. *Glyphyalinia roemeri*												
Glyphyalinia umbilicata					1							
Helicodiscus singleyanus		2										
cf. *Pupisoma dioscoricola*												
Pupoides albilabris												
Strobilops texasiana												
Zonitoides arboreus												
Zonitidae, cf. *Nesovitrea* sp.												
Unident. terrestrial microsnails												
Aquatic microsnails												
Cincinnatia cincinnatiensis												
Gyraulus parvus												
Lymnaeidae, cf. *Fossaria* sp.												
Planorbidae, unidentified												
Pomatiopsis lapidaria												
Valvata tricarinata									1			
Miscellaneous aquatic												
Sphaeriid clams												

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(Table 8.23, continued from previous page)

N112 E99	92.05-92.00	92.00-91.95	91.95-91.90	**Row totals**	**Class totals**
Terrestrial microsnails					**8**
Carychium mexicanum				0	
Catinella vermeta				1	
Gastrocopta contracta				0	
Gastrocopta pellucida				0	
Gastrocopta pentodon (?)				0	
Gastrocopta cf. *G. procera*				0	
Gastrocopta sp.				1	
cf. *Glyphyalinia roemeri*				0	
Glyphyalinia umbilicata				1	
Helicodiscus singleyanus	1	1		4	
cf. *Pupisoma dioscoricola*				0	
Pupoides albilabris				0	
Strobilops texasiana			1	1	
Zonitoides arboreus				0	
Zonitidae, cf. *Nesovitrea* sp.				0	
Unident. terrestrial microsnails				0	
Aquatic microsnails					**1**
Cincinnatia cincinnatiensis				0	
Gyraulus parvus				0	
Lymnaeidae, cf. *Fossaria* sp.				0	
Planorbidae, unidentified				0	
Pomatiopsis lapidaria				0	
Valvata tricarinata				1	
Miscellaneous aquatic					**0**
Sphaeriid clams				0	

(End of Table 8.23)

Table 8.24. Snails Recovered From the Quarter-Inch Screen in N112 E97.

N112 E97	93.14-92.75	92.75-92.70	92.70-92.65	92.65-92.60	92.60-92.55	92.55-92.50	92.50-92.45	92.45-92.40	92.40-92.35	92.35-92.30	92.30-92.25	92.25-92.20	92.20-92.15	**Row totals**	**Class totals**
Terrestrial, large/medium															**1927**
Anguispira strongylodes	88	24	24	12	12	2	1	3		2		7		175	
Euchemotrema leai adults	11	2												13	
Mesodon cf. *M. roemeri*	6													6	
Mesodon cf. *M. thyroidus*														0	
Mesodon sp., fragmentary	4	2	1	1		1								9	
Mesomphix friabilis	149	8	4	4	5	3	1	1				1		176	
Oligyra orbiculata adults	929	62	33	27	14	4	2	1		2	1	1		1076	
Polygyra texasiana adults	156	13	18	7	5	1								200	
Polygyra sp., fragmentary	30	3	5	4	1	1				1	2	1		48	
Praticolella cf *P. pachyloma*	5													5	
Praticolella sp. fragmentary	9				1		1			1		1		13	
Rabdotus sp. adults	54	11	3	1	2			2				1		74	
Rabdotus sp. juveniles	101	6	2	1	2									112	
Rabdotus sp. age class indet.			3			1					1			5	
Unlipped shells	13													13	
Unidentified, terrestrial				2										2	
Aquatic, large/medium															**8**
Helisoma anceps			1									1		2	
Physella virgata														0	
Planorbella trivolvis	5													5	
Planorbidae, unidentified				1										1	
Miscellaneous terrestrial															
Opercula from *O. orbiculata*	149	10	7	3	2						1				172
Terrestrial, large/medium	1555	131	93	59	42	13	5	7	0	6	4	12	0		
Aquatic, large/medium	5	0	1	1	0	0	0	0	0	0	0	1	0		
TOTAL:	1560	131	94	60	42	13	5	7	0	6	4	13	0		

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(Table 8.24, continued from previous page)

N112 E97	93.14-92.75	92.75-92.70	92.70-92.65	92.65-92.60	92.60-92.55	92.55-92.50	92.50-92.45	92.45-92.40	92.40-92.35	92.35-92.30	92.30-92.25	92.25-92.20	92.20-92.15	**Row totals**	**Class totals**
Terrestrial microsnails															**85**
Carychium mexicanum														0	
Catinella vermeta														0	
Gastrocopta contracta	2	1		1	3									7	
Gastrocopta pellucida		1												1	
Gastrocopta pentodon (?)														0	
Gastrocopta cf. *G. procera*														0	
Gastrocopta sp.														0	
cf. *Glyphyalinia roemeri*														0	
Glyphyalinia umbilicata	25		5		4					1				35	
Helicodiscus singleyanus	11	1	4	1	12		1	1		1	1	3		36	
cf. *Pupisoma dioscoricola*														0	
Pupoides albilabris	1													1	
Strobilops texasiana	1													1	
Zonitoides arboreus	1													1	
Zonitidae, cf. *Nesovitrea* sp.		1												1	
Unident. terrestrial microsnails	2													2	
Aquatic microsnails															**2**
Cincinnatia cincinnatiensis														0	
Gyraulus parvus											1			1	
Lymnaeidae, cf. *Fossaria* sp.	1													1	
Planorbidae, unidentified														0	
Pomatiopsis lapidaria														0	
Valvata tricarinata														0	
Miscellaneous aquatic															**0**
Sphaeriid clams														0	

(End of Table 8.24)

Table 8.25. Snails Recovered From the Quarter-Inch Screen in N109 E96.

N109 E96	93.08-93.00	93.00-92.95	92.95-92.90	92.90-92.85	92.85-92.80	92.80-92.75	92.75-92.70	92.70-92.65	92.65-92.60	92.60-92.55	92.55-92.50	92.50-92.45	92.45-92.40
Terrestrial, large/medium													
Anguispira strongylodes	25	20	13	41	97	78	58	56	27	24	22	31	32
Euchemotrema leai adults	1	3	1	1	1	3	4	3		1			
Mesodon cf. *M. roemeri*													
Mesodon cf. *M. thyroidus*		1											
Mesodon sp., fragmentary	6	1	4	3	5	1	1		1	2	1		
Mesomphix friabilis	53	25	22	31	64	28	26	38	18	25	17	17	16
Oligyra orbiculata adults	210	126	99	124	189	138	74	67	52	24	34	36	16
Polygyra texasiana adults	44	23	10	19	41	37	10	15	6	2	6	4	3
Polygyra sp., fragmentary	2	8	10	5	13	16	11	4	2	1	3	6	1
Praticolella cf. *P. pachyloma*	2	4	1					1	2	1			
Praticolella sp., fragmentary	2	1		2	1	5	1	2		1	4	3	3
Rabdotus sp. adults	28	23	7	11	25	19	11	13	4	3	1	6	3
Rabdotus sp. juveniles	32	39	15	23	21	10	8	14	8	8	8	5	11
Rabdotus sp., age class indet.	16	4	5	5	5	3	4	13	2	4	8	10	5
Unlipped shells	1	2	1		1	4		1			1	2	
Unidentified, terrestrial													
Aquatic, large/medium													
Helisoma anceps					1	1	1	1			1		
Physella virgata													
Planorbella trivolvis					1						1		
Planorbidae, unidentified						1	1	1					
Miscellaneous terrestrial													
Opercula from *O. orbiculata*	31	23	30	34	48	24	8	9	7	4	5		1
Terrestrial, large/medium	422	280	188	265	463	342	208	227	122	96	105	120	90
Aquatic, large/medium	0	0	0	0	2	2	2	2	0	0	2	0	0
TOTAL:	422	280	188	265	465	344	210	229	122	96	107	120	90

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(Table 8.25, continued from previous page)

N109 E96	92.40-92.35	92.35-92.30	92.30-92.25	92.25-92.20	92.20-92.15	92.15-92.10	92.10-92.05	92.05-92.00	**Row totals**	**Class totals**
Terrestrial, large/medium										**3022**
Anguispira strongylodes	14	3	9	2	1		2	1	556	
Euchemotrema leai adults									18	
Mesodon cf. *M. roemeri*									0	
Mesodon cf. *M. thyroidus*									1	
Mesodon sp., fragmentary									25	
Mesomphix friabilis	3	5	3	1			1		393	
Oligyra orbiculata adults	5	3	8	2	1	1	2		1211	
Polygyra texasiana adults									220	
Polygyra sp., fragmentary			1					1	84	
Praticolella cf. *P. pachyloma*									11	
Praticolella sp., fragmentary			2				2		29	
Rabdotus sp. adults	1	1	2		1				159	
Rabdotus sp. juveniles	4	2	4			1			213	
Rabdotus sp., age class indet.		1	1				1	2	89	
Unlipped shells									13	
Unidentified, terrestrial									0	
Aquatic, large/medium										**12**
Helisoma anceps	1								6	
Physella virgata		1							1	
Planorbella trivolvis									2	
Planorbidae, unidentified									3	
Miscellaneous terrestrial										
Opercula from *O. orbiculata*	1	1			1					227
Terrestrial, large/medium	27	15	30	5	3	2	8	4		
Aquatic, large/medium	1	1	0	0	0	0	0	0		
TOTAL:	28	16	30	5	3	2	8	4		

(continued on next page)

(Table 8.25, continued from previous page)

N109 E96	93.08-93.00	93.00-92.95	92.95-92.90	92.90-92.85	92.85-92.80	92.80-92.75	92.75-92.70	92.70-92.65	92.65-92.60	92.60-92.55	92.55-92.50	92.50-92.45	92.45-92.40
Terrestrial microsnails													
Carychium mexicanum					2		1						
Catinella vermeta	2	1		2			1						
Gastrocopta contracta	3	1	1		2	8	2	10	4	4	1	6	13
Gastrocopta pellucida		1			3								
Gastrocopta pentodon (?)													
Gastrocopta cf. *G. procera*													
Gastrocopta sp.						1			2				6
cf. *Glyphyalinia roemeri*													
Glyphyalinia umbilicata	8	2	2	6	12	22	8	13		1	1	2	5
Helicodiscus singleyanus	6	5	9	9	30	41	7	25	7	8	6	7	15
cf. *Pupisoma dioscoricola*													
Pupoides albilabris													
Strobilops texasiana				1		2	1	1				1	
Zonitoides arboreus	1												
Zonitidae, cf. *Nesovitrea* sp.													
Unident. terrestrial microsnails					1								
Aquatic microsnails													
Cincinnatia cincinnatiensis	1				1								1
Gyraulus parvus												1	1
Lymnaeidae, cf. *Fossaria* sp.													
Planorbidae, unidentified						1							
Pomatiopsis lapidaria													
Valvata tricarinata													
Miscellaneous aquatic													
Sphaeriid clams										1			

(continued on next page)

(Table 8.25, continued from previous page)

N109 E96	92.40-92.35	92.35-92.30	92.30-92.25	92.25-92.20	92.20-92.15	92.15-92.10	92.10-92.05	92.05-92.00	**Row totals**	**Class totals**
Terrestrial microsnails										**376**
Carychium mexicanum									3	
Catinella vermeta									6	
Gastrocopta contracta	7				4	3	1	2	72	
Gastrocopta pellucida									4	
Gastrocopta pentodon (?)									0	
Gastrocopta cf. *G. procera*									0	
Gastrocopta sp.	1								10	
cf. *Glyphyalinia roemeri*									0	
Glyphyalinia umbilicata	3		1		1			1	88	
Helicodiscus singleyanus	4	2	1	1			1	1	185	
cf. *Pupisoma dioscoricola*									0	
Pupoides albilabris									0	
Strobilops texasiana									6	
Zonitoides arboreus									1	
Zonitidae, cf. *Nesovitrea* sp.									0	
Unident. terrestrial microsnails									1	
Aquatic microsnails										**8**
Cincinnatia cincinnatiensis	1					1			5	
Gyraulus parvus									2	
Lymnaeidae, cf. *Fossaria* sp.									0	
Planorbidae, unidentified									1	
Pomatiopsis lapidaria									0	
Valvata tricarinata									0	
Miscellaneous aquatic										**1**
Sphaeriid clams									1	

(End of Table 8.25)

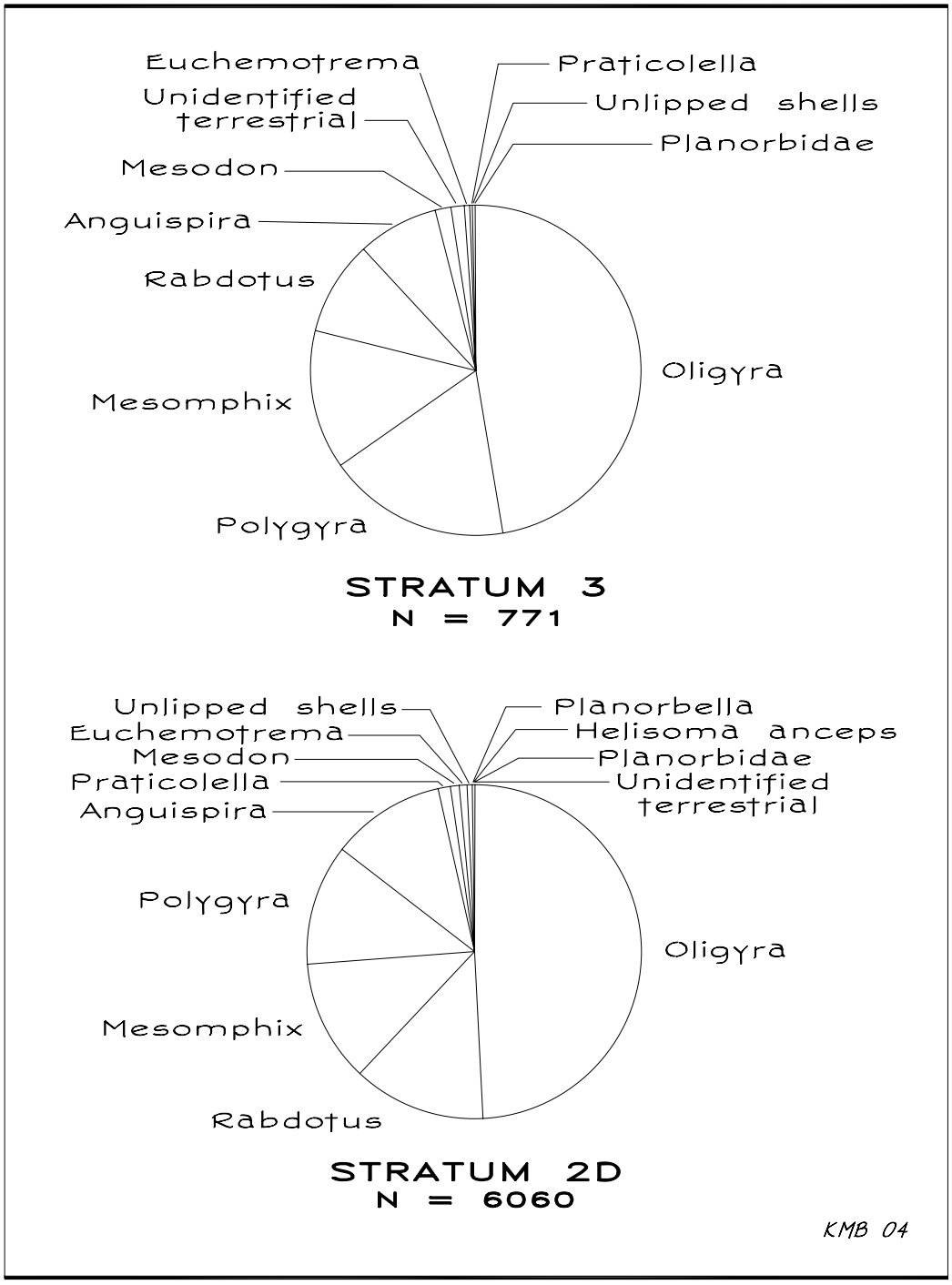

Figure 8.76. Snails Recovered From Quarter-Inch Screen, Strata 2D and 3. Counts combined for all units; fortuitously recovered microsnails omitted.

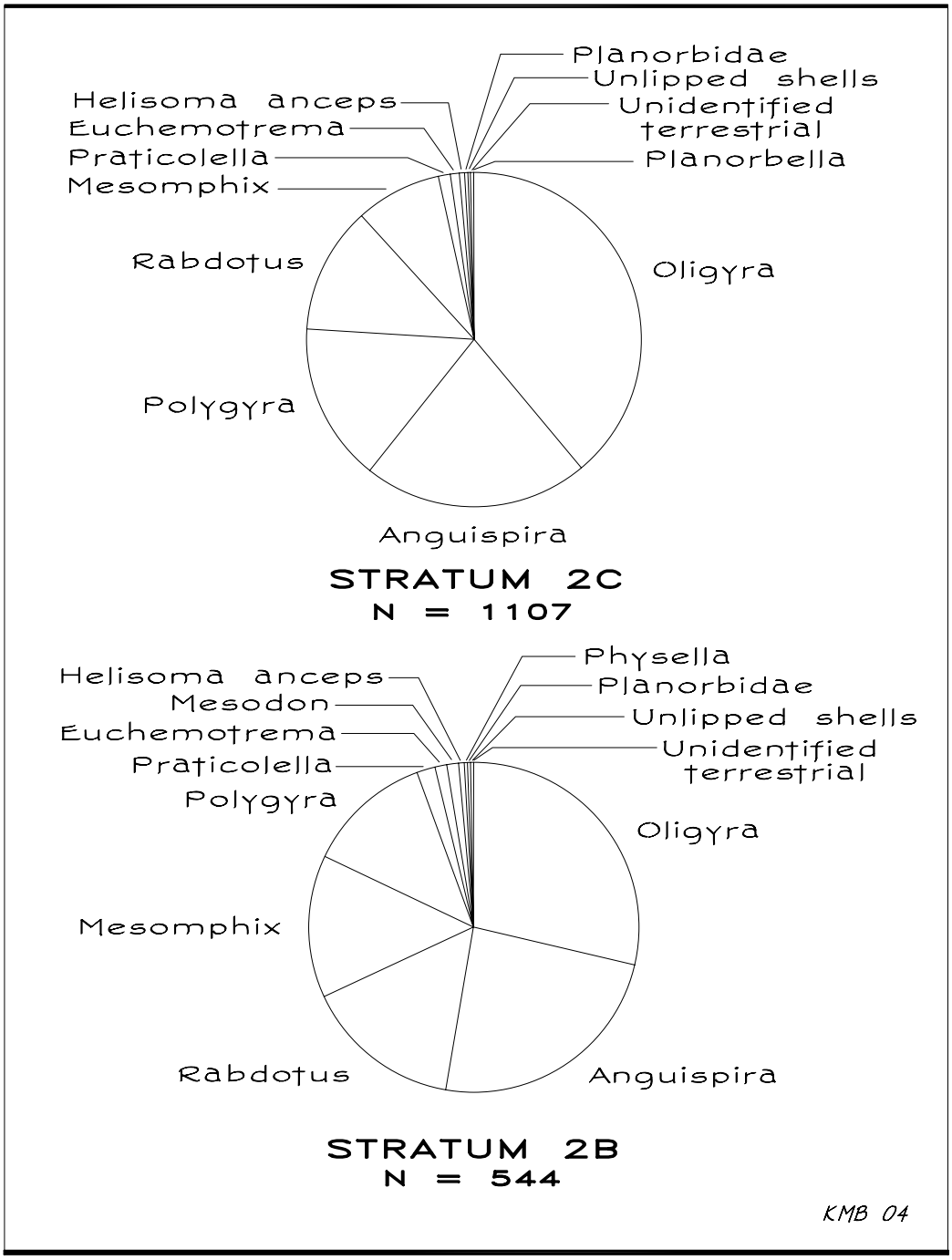

Figure 8.77. Snails Recovered From Quarter-Inch Screen, Strata 2B and 2C. Counts combined for all units; fortuitously recovered microsnails omitted.

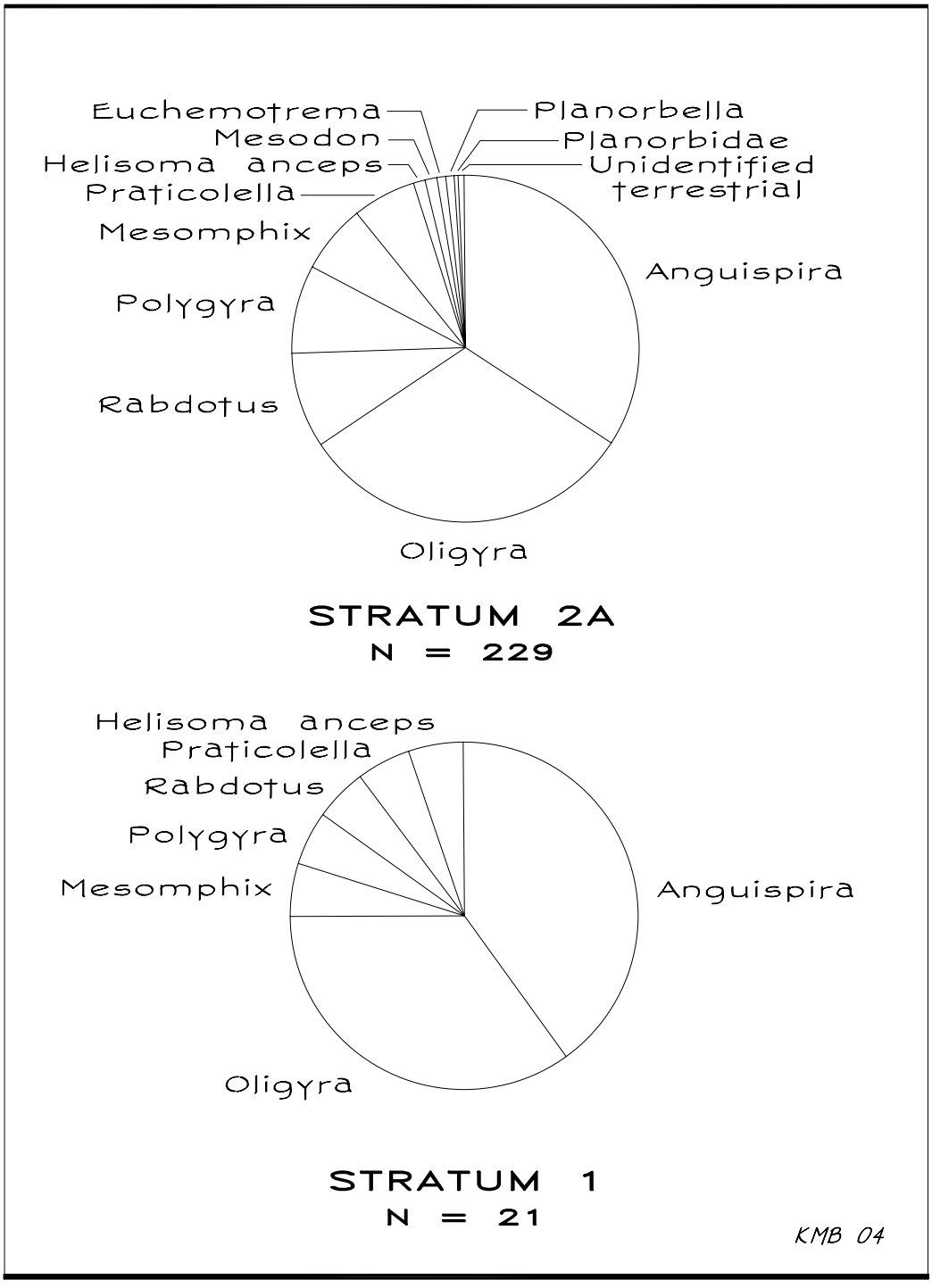

Figure 8.78. Snails Recovered From Quarter-Inch Screen, Strata 1 and 2B. Counts combined for all units; fortuitously recovered microsnails omitted. Note sample size is only 21 specimens.

Cluster Analysis of the Quarter-Inch Screen Sample

Cluster analysis of the quarter-inch screen sample used raw counts (rather than densities or percentages) from 99 cases (excavation levels, mostly 5 cm thick but including some extra thick initial levels) divided into 14 variables (snail taxa or categories, large and medium-bodied only), as follows:

Anguispira strongylodes
Euchemotrema leai aliciae
Mesodon spp.
Mesomphix friabilis
Oligyra orbiculata
Polygyra sp.
Praticolella sp.
Rabdotus sp.
Unlipped shells
Unidentified terrestrial snails
Helisoma anceps
Physella virgata
Planorbella trivolvis
Planorbidae, unidentified

MVSP 3.1 was used for clustering and ordination studies. Both cases (levels) and variables (taxa) were clustered. The 99 levels represent all the excavation levels with at least some snails on the 1/4-inch screen from the six one-meter units studied. A wide variety of distance measures and clustering methods was tried, but the best results seemed to result from Euclidian distance coupled with centroid clustering. Logarithmic and logratio transformations were tried, but the best results came from untransformed data.

When excavation levels were clustered, the resulting dendrogram (too large to reproduce here) shows a great deal of stratigraphic coherency. That is, levels that are in the same stratum tend to cluster together in the same cluster. One major cluster is composed mostly of mixed stratum 2A and 2B levels, another mostly of 2C and 2D

levels, and a fourth mostly of stratum 2D. This suggests that to some extent, the different strata have partly recognizable taxonomic signatures for the large and medium-bodied snail taxa.

When the snail taxa are clustered using the excavation levels as variables (Fig. 8.79), they sort out to a large extent by habitat preference, despite the fact that the data matrix is now unbalanced. Good practice in ordination studies requires more cases than variables, but in this exercise, there are 14 cases (taxa) against 99 variables (excavation levels). Despite this inherently lopsided data matrix, the four aquatic taxa cluster together, joined by *Euchemotrema*, *Mesodon* and *Praticolella*. *Mesomphix* and *Rabdotus* cluster together, joined first by *Polygyra* and then by *Anguispira*. All of these except *Rabdotus* are woodland snails. *Oligyra orbiculata* joins all the others as an outlier, which is appropriate since it is the hardiest and most abundant taxon.

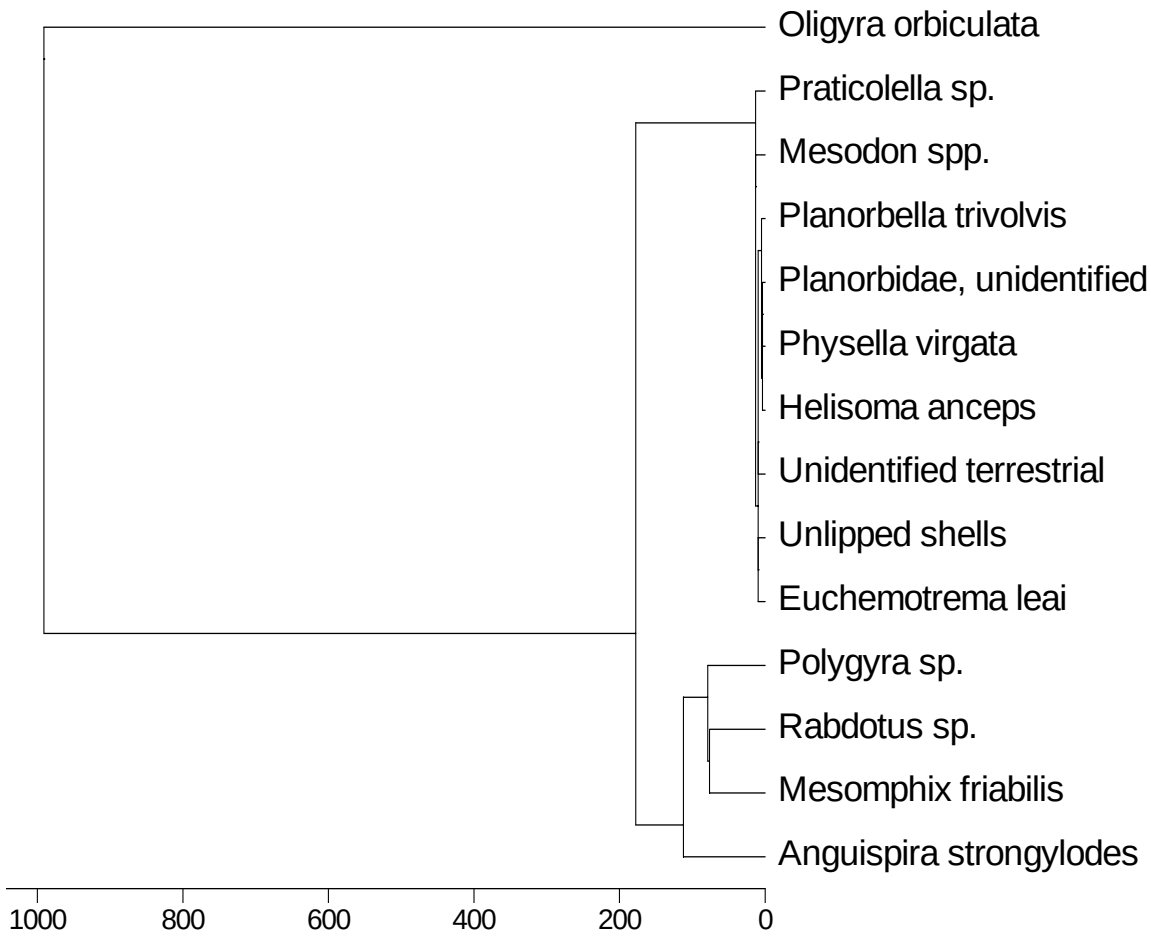

Figure 8.79. Cluster Analysis of Snails From the Quarter-Inch Screen. Clustering by variables using the centroid method and a Euclidian distance function (scale at bottom). MVSP 3.1 analysis uses 14 variables (taxa) and 99 cases (excavation levels).

Correspondence Analysis of the Quarter-Inch Screen Sample

The correspondence analysis option in MVSP 3.1 was used to analyze the same data matrix used for cluster analysis. Without detrending or downweighting of rare taxa, the first three axes extracted account for only 53% of the variance in the matrix,

indicating that spatial patterning of the large and medium-bodied snail taxa is only moderately well developed, and nearly half of the variance remains unexplained.

Detrending and downweighting of rare taxa increases the explained variance to about 58%, but results in a much less interpretable solution, so this option was not used. Table 8.26 shows variable scores for the first three axes. These axes are interpreted as follows:

Axis 1: aquatic and deciduous woodland taxa

High positive loadings	
Physella virgata (aquatic)	7.405
Helisoma anceps (aquatic)	4.503
Anguispira strongylodes (terrestrial, woodland)	2.202
Praticolella sp. (well-drained, open)	1.274
Planorbidae, unidentified (aquatic)	1.091
Planorbella trivolvis (aquatic)	0.618
High negative loadings	
Oligyra orbiculata (grassland or open woodland)	-0.708

Axis 2: dry woodland? (interpretation uncertain)

High positive loadings	
Physella virgata (aquatic)	53.764
Mesomphix friabilis (terrestrial, woodland)	0.921
Praticolella sp. (well-drained, open)	0.837
Rabdotus sp. (grassland or open woodland)	0.825
High negative loadings	
Planorbidae, unidentified (aquatic)	-3.125
Helisoma anceps (aquatic)	-1.757
Planorbella trivolvis (aquatic)	-1.409
Polygyra sp. (terrestrial, woodland)	-0.762

Axis 3: xeric, drought-adapted

High positive loadings	
Praticolella sp. (well-drained, open)	6.868
Planorbella trivolvis (aquatic)	3.836

Rabdotus sp. (grassland or open woodland)	0.605
Oligyra orbiculata (grassland or open woodland)	0.107
<u>High negative loadings</u>	
Physella virgata (aquatic)	-21.013
Planorbidae, unidentified (aquatic)	-3.729

Axis 1 (31% of variance) has a strong aquatic component, along with *Anguispira strongylodes*, an important woodland taxon, although two other woodland taxa, *Mesomphix* and *Mesodon*, contribute little. *Oligyra*, a drought-adapted taxon, has a negative loading.

Axis 2 (12% of variance) is difficult to interpret but seems to feature taxa (*Mesomphix, Praticolella*, *Rabdotus*) that may be found in open, somewhat dry, well-drained woodland. The high loading for *Physella virgata* is not thought to be meaningful.

Axis 3 (10% of variance) is more interpretable and seems to feature drought-adapted taxa (*Praticolella*, *Rabdotus*, *Oligyra*) found in open terrain (grassland or open xeric woodland).

Case scores from the correspondence analysis can be plotted two different ways: as a bi-axis scattergram (Figs.8.80, 8.81) or as vertical curves representing each axis. Figures 8.82 and 8.83 are vertical plots of the case scores for each of the three axes for the 1/4-inch screen sample from N109 E103 and N110 E102. Both of these plots (as well plots for other excavation units, not shown here) indicate the axis 1 scores show a slight upward-declining trend. This probably indicates the declining importance of aquatic and woodland taxa toward the upper part of the bench deposits, perhaps as a result of long-

term drying of the habitat. All three axes show more variability at the base of the section, perhaps because of small sample sizes.

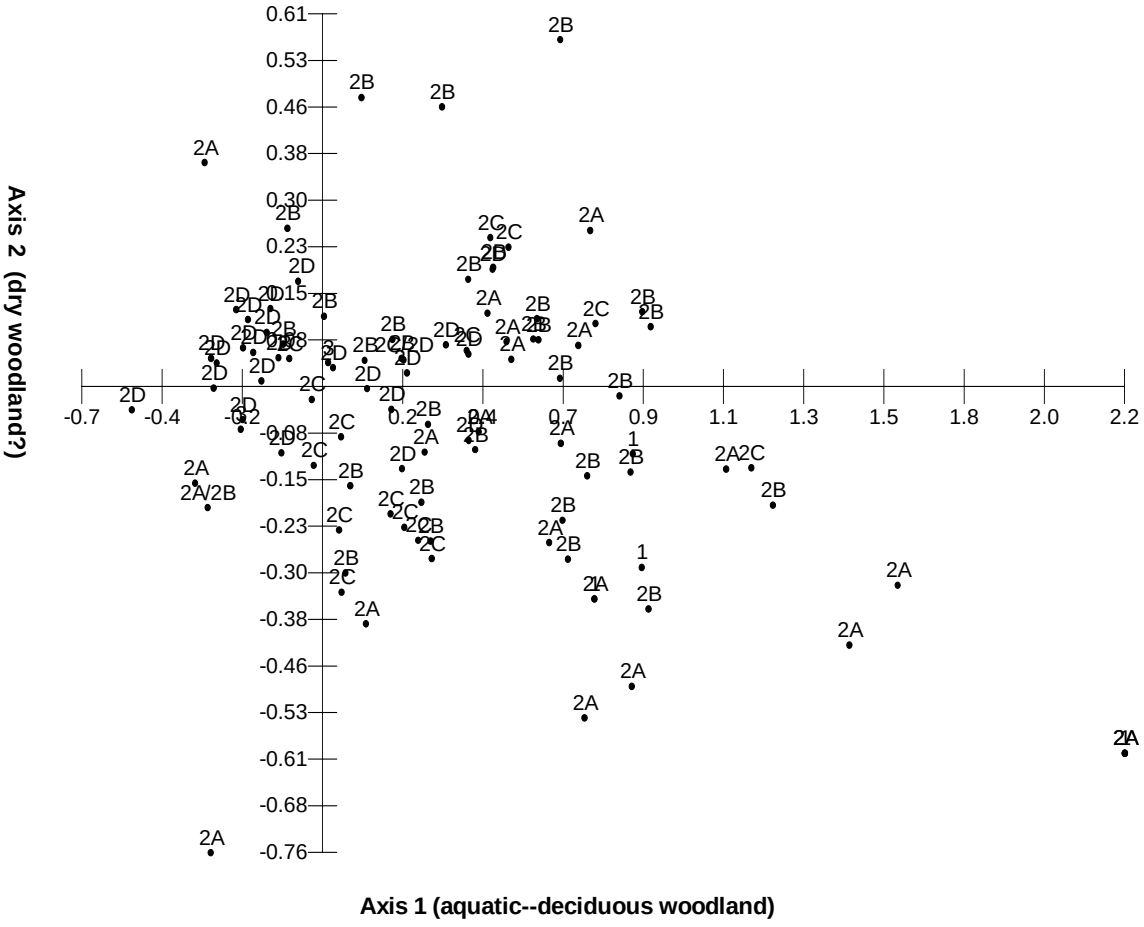

Figure 8.80. Correspondence Analysis of Snails From the Quarter-Inch Screen. Plot of cases (excavation levels identified by stratum) on the first two axes.

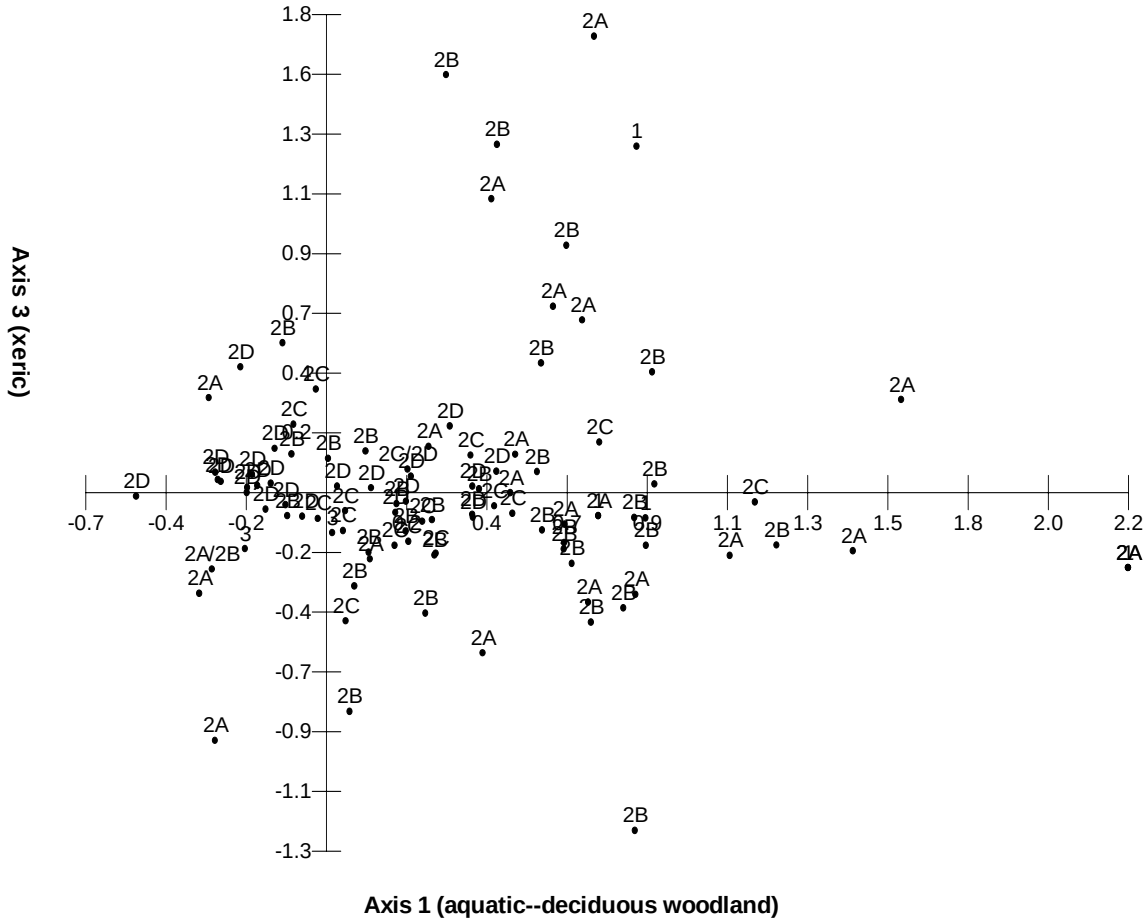

Figure 8.81. Correspondence Analysis of Snails From the Quarter-Inch Screen. Plot of cases (excavation levels identified by stratum) on the first and third axes.

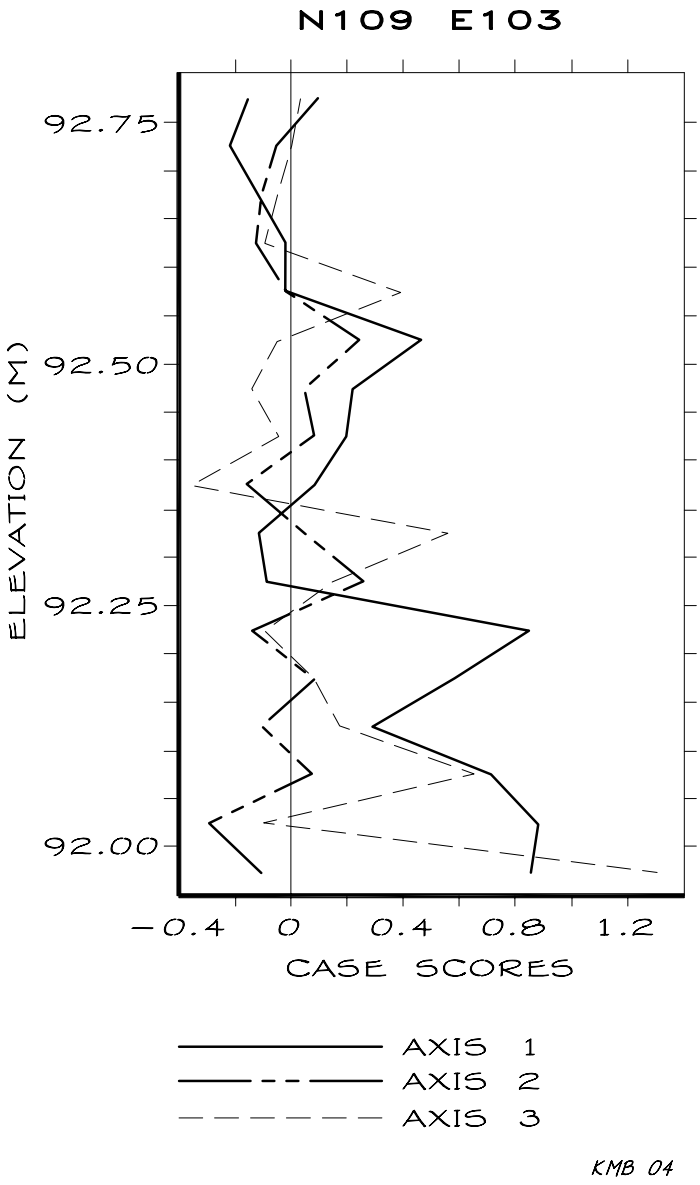

Figure 8.82. Vertical Plot of First Three Axes, N109 E103. Case scores from correspondence analysis of snails from the quarter-inch screen are shown. Note axis 1 (aquatic and deciduous woodland taxa) tends to decline upward, suggesting progressive drying of the habitat, although axis 3 (xeric taxa) does not increase upward.

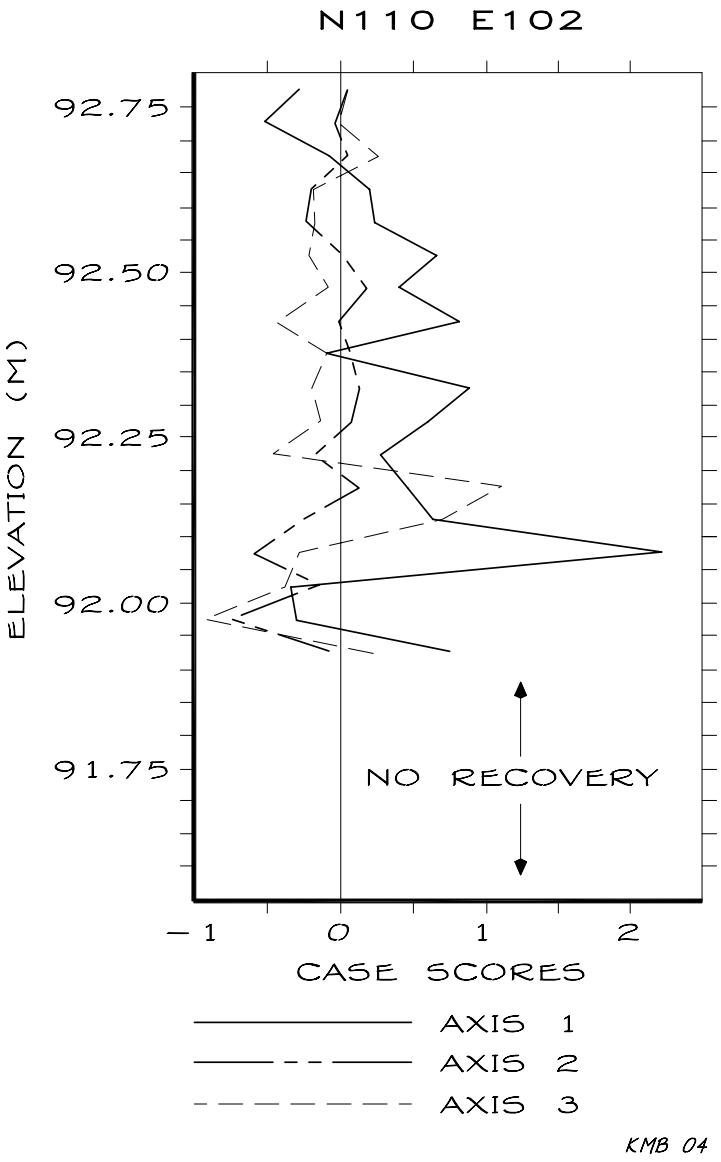

Figure 8.83. Vertical Plot of First Three Axes, N110 E102. Case scores from correspondence analysis of snails from the quarter-inch screen are shown. Vertical patterns here are similar to the previous figure. No snails were recovered from the quarter-inch screen in the lower levels of this unit.

Table 8.26. Correspondence Analysis of Snail Taxa From the Quarter-Inch Screen.

	Axis 1	Axis 2	Axis 3
Eigenvalues	0.101	0.040	0.035
Percentage	30.52	12.01	10.48
Cumulative Percentage	30.52	42.52	62.27

Variable scores	Axis 1	Axis 2	Axis 3
Anguispira strongylodes	2.202	-0.599	-0.284
Euchemotrema leai aliciae	0.058	0.062	-0.346
Mesodon spp.	-0.361	0.059	-0.788
Mesomphix friabilis	0.285	0.921	-0.250
Oligyra orbiculata	-0.708	-0.096	0.107
Polygyra sp.	-0.305	-0.762	-0.935
Praticolella sp.	1.274	0.837	6.868
Rabdotus sp.	0.064	0.825	0.605
Unlipped shells	-1.061	0.537	0.994
Unidentified terrestrial	-1.368	-2.154	-6.977
Helisoma anceps	4.503	-1.757	0.126
Physella virgata	7.405	53.764	-21.013
Planorbella trivolvis	0.618	-1.409	3.836
Planorbidae, unidentified	1.091	-3.125	-3.729

Notes: no detrending, no downweighting of rare taxa, maximum of five axes; 14 variables (taxa), 99 cases (excavation levels).

SNAILS FROM SIEVED MATRIX COLUMNS

Two columns of sediment samples from the southwest corners of the two deepest excavation units were selected for fine mesh sieving (Table 8.27):

1) N109 E103. This column consists of 21 samples. The uppermost is a large sample (19.651 kg dry weight) from an initial level 24 cm thick. Samples below that average 2.938 kg in size (range, 2.160-3.972 kg; total column weight, 69.419 kg).

2) N110 E102. This column consists of 26 samples. The average dry sample weight is 2.642 kg (range, 1.546-5.446 kg; total column weight, 68.699 kg). All samples were 5 cm thick except for the uppermost sample, which was 10 cm thick.

Table 8.27. Snail Matrix Sample Weights.

N109 E103		N110 E102	
Sample	Sample weight (kg)	Sample	Sample weight (kg)
93.14-92.90	10.6505	92.90-92.80	3.6843
92.90-92.85	3.8481	92.80-92.75	3.2173
92.85-92.80	2.7402	92.75-92.70	2.7360
92.80-92.75	2.5968	92.70-92.65	3.7962
92.75-92.70	2.3000	92.65-92.60	2.5090
92.70-92.65	3.2022	92.60-92.55	3.1265
92.65-92.60	2.3660	92.55-92.50	5.4457
92.60-92.55	3.4702	92.50-92.45	2.3718
92.55-92.50	2.6793	92.45-92.40	3.0752
92.50-92.45	2.1602	92.40-92.35	2.1275
92.45-92.40	3.0355	92.35-92.30	2.2745
92.40-92.35	3.0615	92.30-92.25	2.4850
92.35-92.30	3.7583	92.25-92.20	2.6632
92.30-92.25	2.7275	92.20-92.15	2.8249
92.25-92.20	2.8668	92.15-92.10	2.2875
92.20-92.15	3.0167	92.10-92.05	2.5500
92.15-92.10	3.9715	92.05-92.00	2.6697
92.10-92.05	2.4515	92.00-91.95	2.3585
92.05-92.00	2.4803	91.95-91.90*	2.1247
92.00-91.95	3.5868	91.90-91.85	2.4370
91.95-91.90	2.4485	91.85-91.80	1.5630
		91.80-91.75	2.1510
		91.75-91.70	2.3854
		91.70-91.65	1.5455
		91.65-91.60	2.2685
		91.60-91.55	2.0215

* Floated snails from this sample lost during lab processing.

Extraction Methods

The thoroughly dried sediment (stored in paper bags for about nine months) was first weighed on a triple beam balance, then soaked in a dispersant solution of water and dishwasher detergent, to break clay bonds in the sediment. Soaking times varied from a few hours to one or two days. Generally a few snail shells lacking trapped sediment would break free and float to the top of the container as soon as the sample was poured into the dispersant. By experimentation, it was found that repeated gentle stirring and skimming with a fine mesh strainer recovered most of the smaller species at this stage.

After soaking, and after repeated stirring of the bottom sludge failed to release any additional snails, the sludge was gradually poured into nested #12 (1.7 mm mesh) and #35 (0.5 mm) geologic sieves. The coarser #12 sieve served to catch the larger snails, rocks, and rhizoconcretions which might clog the finer screen. The mesh size of the #35 screen is small enough to retain shells of the smallest species.

After all of the sediment was washed through the sieves, the residue was dried and the coarse fraction was hand picked for shells and shell fragments. The fine fraction, that retained on the #35 sieve, consisted mostly of coarse to fine sand and rhizoconcretions, since most of the smaller shells had already floated free. However, some shells of smaller species with entrapped sediment were still present, and in order to recover these, the dried fine residue was poured into a saturated warm salt solution. The absence of trapped water in the shells and the increased specific gravity of the solution helped release a few additional small shells at this final stage of recovery.

Recovery is believed to be nearly complete for whole shells and most shell fragments over 1.7 mm across. Recovery of whole shells should be nearly complete for species 0.5-1.7 mm across. Spot inspection of fine residue samples revealed many small fragments from larger species, but no whole snail shells. The extraction process, then, yielded three fractions from each sample:

1) whole shells and some larger fragments larger than 1.7 mm
2) whole shells 0.5-1.7 mm, non-floating
3) whole shells 0.5-1.7 mm, floating

These three fractions were given to Raymond Neck for sorting and identification. After identification, the fractions were tabulated separately, but I have combined the counts from the separate fractions for analysis and ordination studies. Tables 8.28 and 8.29 show the results for these two matrix columns. There are 31 taxa. For the most part, I have left the species assignments as defined by Neck, although I suspect that the *Praticolella* are actuall*y P. pachyloma*, and the *Polygyra* are *P. texasiana triodontoides*.

Looking at the two matrix columns combined, across all strata, the snail taxa are mostly a mixture of 1) cosmopolitan, drought-resistant, open terrain species 2) deciduous woodland species, and 3) aquatic species (Fig. 8.84).

Cosmopolitan, drought-resistant snails of two species (*Helicodiscus singleyanus* and *Oligyra orbiculata*) make up about 60% of the total from the matrix columns. However, the abundance of these snails may be misleading. Although no data on reproduction rates are available, it seems likely that both species are prolific breeders adapted to unpredictable climatic conditions. It may be the case that both resemble r-selected species, producing large numbers of offspring to compensate for high juvenile

mortality, in which case large sample numbers might overstate the importance of the species in the snail fauna.

The four next most abundant taxa (*Anguispira strongylodes*, *Gastrocopta contracta*, *Carychium mexicanum*, and *Glyphyalinia umbilicata*) are deciduous woodland or wet floodplain species accounting for another 26% of the total. The remaining taxa are a mixture of woodland, open terrain, amphibious and aquatic snails, most of them accounting for less than 1% each of the total (Fig. 8.84). Of particular interest are the relatively large numbers of *Carychium mexicanum* recovered from the matrix columns. This species is a good indicator of wet floodplain habitats. The most abundant aquatic snail is *Cincinnatia integra*, accounting for just over 1% of the total.

Table 8.28. Snails Extracted From Sieved Matrix Samples, N109 E103.

N109 E103	*Anguispira strongylodes*	*Carychium mexicanum*	*Catinella vermeta*	*Euchemotrema leai aliciae*	*Gastrocopta armifera*	*Gastrocopta contracta*	*Gastrocopta pellucida*	*Gastrocopta pentodon*	*Gastrocopta procera*	*Gastrocopta tappaniana*	*Hawaiia minuscula*	*Helicodiscus singleyanus*	*Mesodon thyroidus*	*Mesomphix friabilis*	*Pomatiopsis lapidaria*	*Pupisoma dioscoricola*	*Strobilops texasiana*
93.14-92.90 3/2D	38	1	0	3	0	26	5	0	0	0	1	66	0	26	0	0	2
92.90-92.85 2D	25	4	0	1	0	14	1	0	1	0	0	77	0	20	0	0	0
92.85-92.80 2D	18	1	0	1	0	4	0	0	2	0	0	61	0	2	0	0	0
92.80-92.75 2D	8	2	0	1	0	8	2	0	4	0	0	54	0	2	0	0	0
92.75-92.70 2D	7	1	0	0	0	0	0	0	1	0	0	32	1	2	0	0	0
92.70-92.65 2D	4	0	0	0	0	2	0	0	0	0	0	30	0	0	0	0	0
92.65-92.60 2C	6	3	1	1	0	3	0	0	0	0	0	30	0	1	0	0	0
92.60-92.55 2C	13	3	1	1	0	10	1	0	1	0	0	46	0	3	0	0	0
92.55-92.50 2B	13	19	0	0	0	7	0	0	0	0	1	68	0	4	0	0	0
92.50-92.45 2B	3	15	0	0	0	12	0	0	1	0	0	79	0	4	0	0	0
92.45-92.40 2B	10	14	0	1	0	16	0	0	2	1	0	71	0	3	0	1	1
92.40-92.35 2B	3	9	0	0	1	8	0	0	4	0	0	68	0	2	0	0	0
92.35-92.30 2B	4	0	1	0	0	17	0	0	0	0	0	31	0	2	0	0	1
92.30-92.25 2B	4	9	0	0	0	6	0	0	0	0	0	54	0	2	0	1	4
92.25-92.20 2B	14	3	0	0	0	11	0	0	2	0	0	55	0	6	0	1	1
92.20-92.15 2A/2B	15	8	1	1	0	0	0	0	3	0	0	45	0	1	0	1	1
92.15-92.10 2A	13	6	0	0	0	6	0	0	0	0	0	61	0	4	0	0	2
92.10-92.05 2A	13	9	0	0	0	9	0	0	0	0	0	72	0	5	0	0	0
92.05-92.00 2A	17	7	0	0	0	6	1	0	2	0	0	50	0	5	0	1	3
92.00-91.95 1	9	0	0	0	0	2	0	0	0	0	0	32	0	2	0	0	1
91.95-91.90 1	3	13	0	0	0	2	0	0	0	0	0	34	0	0	1	0	0
Column totals:	240	127	4	10	1	169	10	0	23	1	2	1116	1	96	1	5	16

(continued on next page)

(Table 8.28, continued from previous page)

N109 E103	*Glyphyalinia umbilicata*	*Oligyra orbiculata*	*Polygyra mooreana*	*Polygyra texasiana*	*Praticolella berlandieriana*	*Pupoides albilabris*	*Rabdotus sp.*	*Zonitoides arboreus*	*Biomphalaria obstructa*	*Gyraulus parvus*	*Planorbella trivolvis*	*Physella virgata*	*Cincinnatia integra*	*Valvata tricarinata*	Row totals
93.14-92.90 3/2D	8	69	16	0	0	1	35	0	0	1	1	0	0	0	299
92.90-92.85 2D	11	40	9	0	0	4	8	0	0	1	0	0	0	0	216
92.85-92.80 2D	9	20	5	0	1	4	4	0	1	0	0	0	0	0	133
92.80-92.75 2D	3	22	5	0	1	0	6	0	0	0	1	0	0	0	119
92.75-92.70 2D	4	23	3	0	0	3	5	1	0	0	0	0	0	0	83
92.70-92.65 2D	2	13	11	0	1	1	5	1	0	0	1	0	0	0	71
92.65-92.60 2C	6	13	4	0	2	0	6	0	0	0	0	0	0	0	76
92.60-92.55 2C	1	8	1	0	0	0	0	0	0	0	0	0	0	0	89
92.55-92.50 2B	4	7	1	0	0	0	2	0	0	0	0	0	0	0	126
92.50-92.45 2B	1	3	3	0	0	0	1	0	0	0	0	0	0	0	122
92.45-92.40 2B	13	2	0	0	0	0	2	0	0	0	0	0	0	0	137
92.40-92.35 2B	10	3	0	0	0	3	3	0	0	0	0	0	0	0	114
92.35-92.30 2B	10	5	1	0	0	3	4	0	0	0	2	0	0	0	81
92.30-92.25 2B	5	3	0	0	0	0	0	0	0	1	0	0	0	0	89
92.25-92.20 2B	2	4	0	0	0	2	3	0	0	2	0	0	10	0	116
92.20-92.15 2A/2B	6	4	4	0	0	0	5	0	0	0	2	0	4	0	101
92.15-92.10 2A	8	9	2	0	0	0	2	0	0	0	1	0	6	0	120
92.10-92.05 2A	8	2	0	0	0	2	0	0	0	0	1	0	3	1	125
92.05-92.00 2A	6	6	0	0	0	1	3	0	0	1	1	0	2	0	112
92.00-91.95 1	8	4	0	0	0	0	0	0	0	0	1	0	8	0	67
91.95-91.90 1	0	3	0	0	0	0	0	0	0	0	0	0	6	0	62
Column totals:	125	263	65	0	5	24	94	2	1	6	11	0	39	1	2458

(End of Table 8.28)

Table 8.29. Snails Extracted From Sieved Matrix Samples, N110 E102.

N110 E102	*Anguispira strongylodes*	*Carychium mexicanum*	*Catinella vermeta*	*Euchemotrema leai aliciae*	*Gastrocopta armifera*	*Gastrocopta contracta*	*Gastrocopta pellucida*	*Gastrocopta pentodon*	*Gastrocopta procera*	*Gastrocopta tappaniana*	*Hawaiia minuscula*	*Helicodiscus singleyanus*	*Mesodon thyroidus*	*Mesomphix friabilis*	*Pomatiopsis lapidaria*	*Pupisoma dioscoricola*	*Strobilops texasiana*
92.90-92.80 2D	9	0	0	0	0	7	1	0	2	0	0	50	1	3	0	0	1
92.80-92.75 2D	0	0	0	0	0	2	0	0	1	0	0	36	0	2	0	0	0
92.75-92.70 2D	0	0	1	0	0	1	0	0	0	0	0	51	0	0	0	1	0
92.70-92.65 2C	3	0	0	0	0	1	0	0	0	0	0	72	0	0	0	0	1
92.65-92.60 2C	11	1	0	0	0	5	1	0	0	0	0	82	0	8	0	0	0
92.60-92.55 2C	12	8	0	0	0	8	0	0	0	0	0	104	0	8	0	0	0
92.55-92.50 2B/2C	11	32	0	1	0	30	0	0	0	0	0	134	0	6	0	0	0
92.50-92.45 2B	7	19	0	0	0	14	0	1	0	0	0	98	0	2	0	0	1
92.45-92.40 2B	11	39	0	0	0	24	0	0	0	0	0	125	0	2	0	0	0
92.40-92.35 2B	3	14	0	0	0	10	0	0	0	0	0	74	0	0	0	0	0
92.35-92.30 2B	5	13	0	0	0	7	0	0	0	0	0	56	0	1	0	0	0
92.30-92.25 2B	12	6	0	0	0	9	0	0	1	0	0	68	0	1	0	0	0
92.25-92.20 2B	19	7	0	0	0	5	0	0	0	0	0	60	0	4	1	0	0
92.20-92.15 2B	10	10	0	0	0	18	0	0	0	0	0	55	0	2	1	1	0
92.15-92.10 2A	6	9	0	1	0	11	0	0	0	0	0	30	0	4	0	0	2
92.10-92.05 2A	6	17	0	1	0	3	0	0	0	0	0	54	0	3	1	0	3
92.05-92.00 2A	5	6	0	0	0	12	0	0	0	0	0	35	0	1	0	0	2
92.00-91.95 2A/calc	0	6	0	0	0	5	0	0	0	0	0	30	0	1	0	0	0
91.95-91.90 calc	0	1	0	0	0	0	0	0	0	0	0	17	0	0	0	0	0
91.90-91.85 calc	1	4	0	0	0	1	0	0	0	0	0	25	0	0	0	0	0
91.85-91.80 1	1	8	0	0	0	1	0	0	0	0	0	27	0	0	1	2	0
91.80-91.75 1	0	3	0	0	0	1	0	0	0	0	0	31	0	5	0	0	0
91.75-91.70 1	0	3	0	0	0	1	0	0	0	0	0	28	0	0	0	0	0
91.70-91.65 1	0	1	0	0	0	1	0	0	0	0	0	13	0	0	0	0	1
91.65-91.60 1	0	1	0	0	0	0	0	0	0	0	0	21	0	0	0	0	0
91.60-91.55 1	0	1	0	0	0	1	0	0	0	0	1	34	0	0	0	0	1
Column totals:	132	209	1	3	0	178	2	1	4	0	1	1410	1	53	4	4	12

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(Table 8.29, continued from previous page)

N110 E102	*Glyphyalinia umbilicata*	*Oligyra orbiculata*	*Polygyra mooreana*	*Polygyra texasiana*	*Praticolella berlandieriana*	*Pupoides albilabris*	*Rabdotus sp.*	*Zonitoides arboreus*	*Biomphalaria obstructa*	*Gyraulus parvus*	*Planorbella trivolvis*	*Physella virgata*	*Cincinnatia integra*	*Valvata tricarinata*	Row totals
92.90-92.80 2D	7	6	2	3	0	1	12	0	0	0	0	0	2	0	107
92.80-92.75 2D	6	9	1	2	0	0	5	0	0	0	0	0	1	0	65
92.75-92.70 2D	3	10	1	0	0	0	1	0	0	0	0	1	0	0	70
92.70-92.65 2C	4	10	3	5	0	0	5	0	0	0	1	0	1	0	106
92.65-92.60 2C	4	11	10	0	0	0	3	0	0	0	1	0	0	0	137
92.60-92.55 2C	9	20	2	0	1	0	2	0	0	0	1	0	0	0	175
92.55-92.50 2B/2C	7	19	4	0	0	0	3	0	0	0	0	0	0	0	247
92.50-92.45 2B	7	9	0	0	2	1	0	0	0	0	0	0	0	0	161
92.45-92.40 2B	17	7	1	0	3	1	1	0	0	0	0	0	0	0	231
92.40-92.35 2B	11	2	0	0	0	0	1	0	0	0	0	0	0	0	115
92.35-92.30 2B	11	4	1	0	0	0	0	1	0	0	0	0	0	0	99
92.30-92.25 2B	2	1	2	0	0	2	5	0	0	0	3	0	3	0	115
92.25-92.20 2B	4	3	0	0	0	0	4	0	0	0	0	0	3	0	110
92.20-92.15 2B	2	8	0	0	0	0	4	0	0	1	5	0	0	0	117
92.15-92.10 2A	3	9	1	0	0	0	3	0	1	1	2	0	0	0	83
92.10-92.05 2A	9	5	2	0	0	0	2	1	0	0	0	0	0	0	107
92.05-92.00 2A	3	4	0	0	1	0	3	0	1	0	0	0	1	1	75
92.00-91.95 2A/calc	1	3	0	0	0	1	3	0	0	0	1	0	0	0	51
91.95-91.90 calc	0	1	0	0	0	0	2	0	0	0	0	0	0	0	21
91.90-91.85 calc	0	0	0	0	0	0	1	0	0	0	1	0	1	0	34
91.85-91.80 1	1	0	0	0	0	0	0	0	0	3	2	0	1	0	47
91.80-91.75 1	0	16	3	0	1	1	4	0	0	0	0	0	0	0	65
91.75-91.70 1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	33
91.70-91.65 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16
91.65-91.60 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22
91.60-91.55 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	38
Column totals:	111	157	33	10	8	7	64	2	2	5	17	1	13	2	2447

(End of Table 8.29)

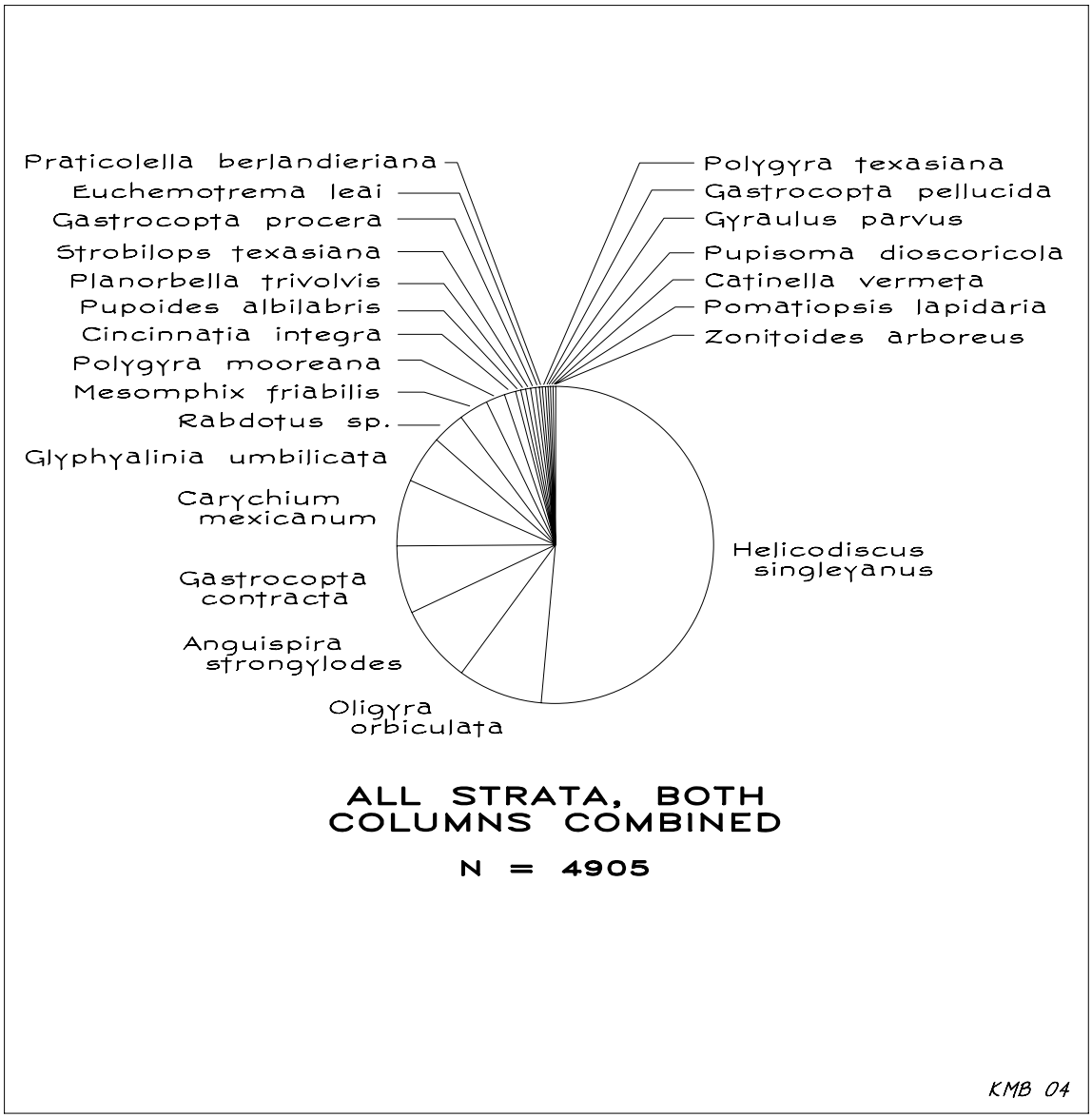

Figure 8.84. Percentage Composition of Combined Matrix Columns. Proportional representation of species in both matrix columns combined, across all strata.

Figures 8.85-8.87 show the taxonomic composition broken down by strata. *Helicodiscus singleyanus* is the most abundant species in all except the uppermost diagram (Fig. 8.85, *top*), which illustrates a single excavation level, the uppermost level (N109 E103, 93.14-92.90 m), consisting mostly of stratum 3 and a small amount of stratum 2D sediment. *Oligyra orbiculata* is the most abundant species here. These diagrams show that next to *Helicodiscus*, the next most abundant species are mostly woodland taxa (*Carychium*, *Anguispira*, *Gastrocopta contracta*, *Glyphyalinia*, *Mesomphix*) and a few more drought-tolerant (*Oligyra*, *Rabdotus*) or aquatic (*Cincinnatia*) taxa.

There are a few stratigraphic trends that are apparent from these pie charts. *Carychium mexicanum*, a mesic floodplain forest species, is abundant in the three lowest strata, declining in importance in stratum 2C and above. At the same time, *Oligyra orbiculata* takes its place as a second-ranked species in stratum 2C and increases in importance toward the top of the columns. This seems to be clear evidence of increased drying of the habitat. However, *Anguispira strongylodes*, another woodland species, also becomes more abundant toward the top of the columns.

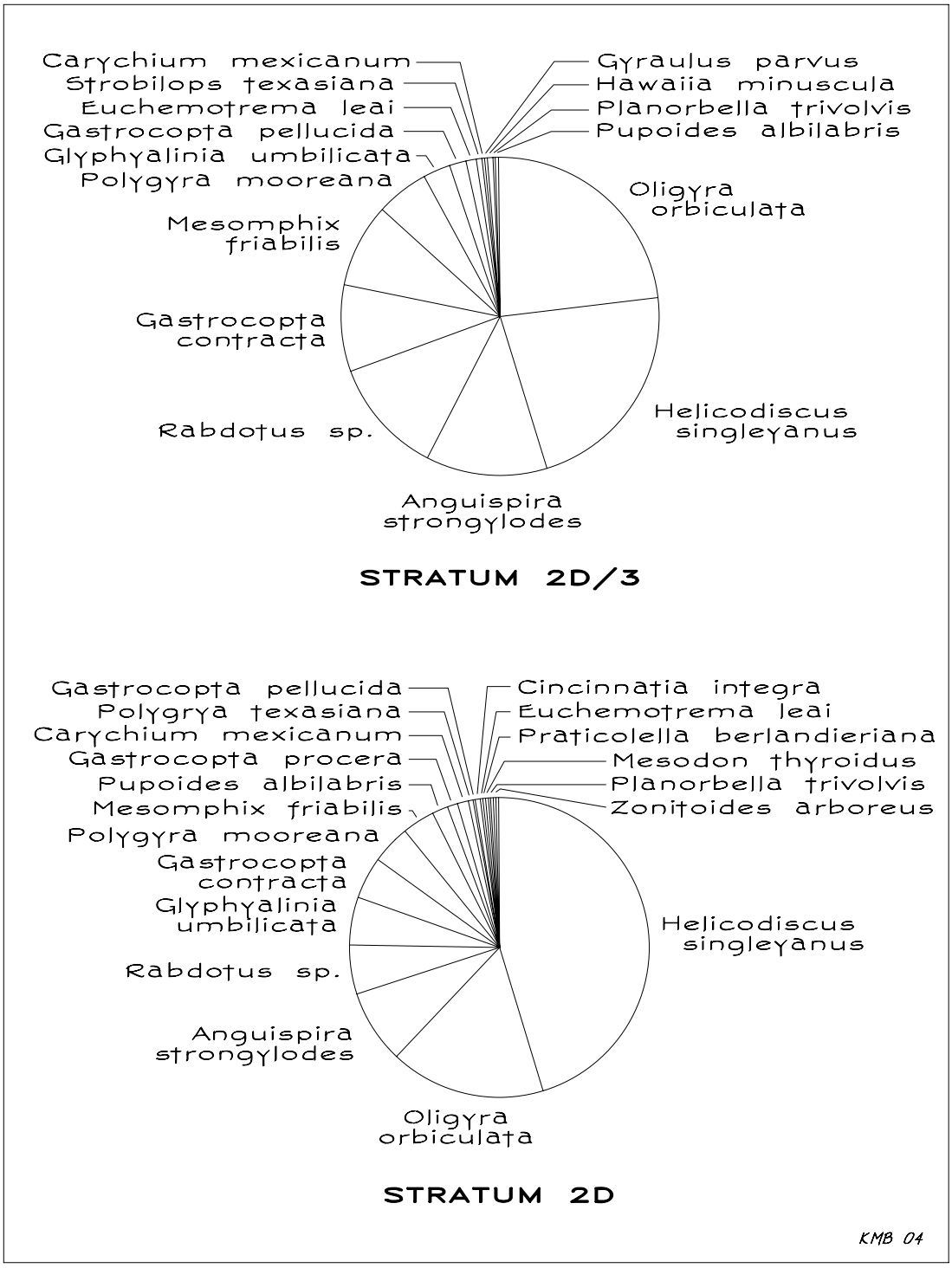

Figure 8.85. Taxonomic Composition of Matrix Columns, Strata 2D and 2D/3.

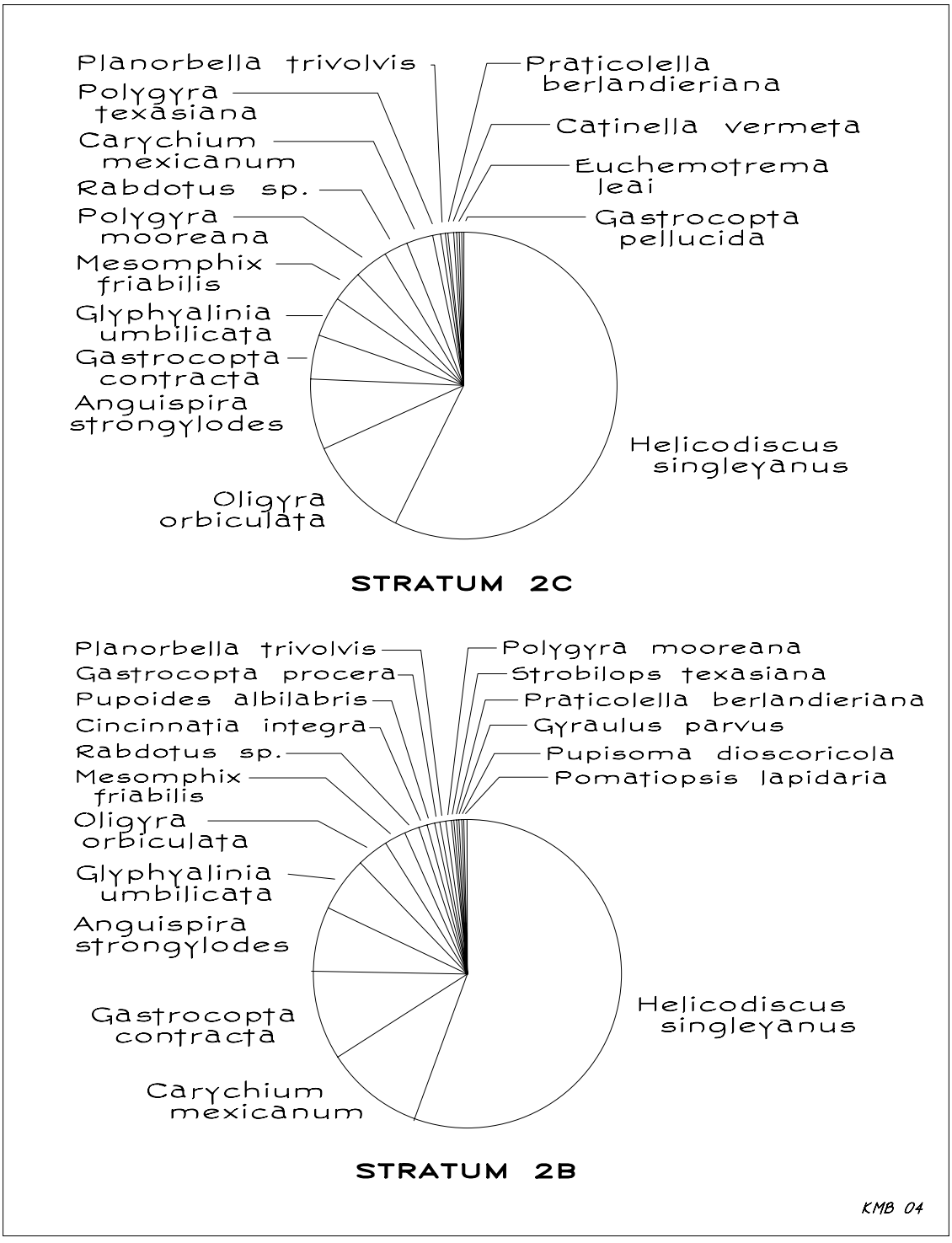

Figure 8.86. Taxonomic Composition of Matrix Columns, Strata 2B and 2C.

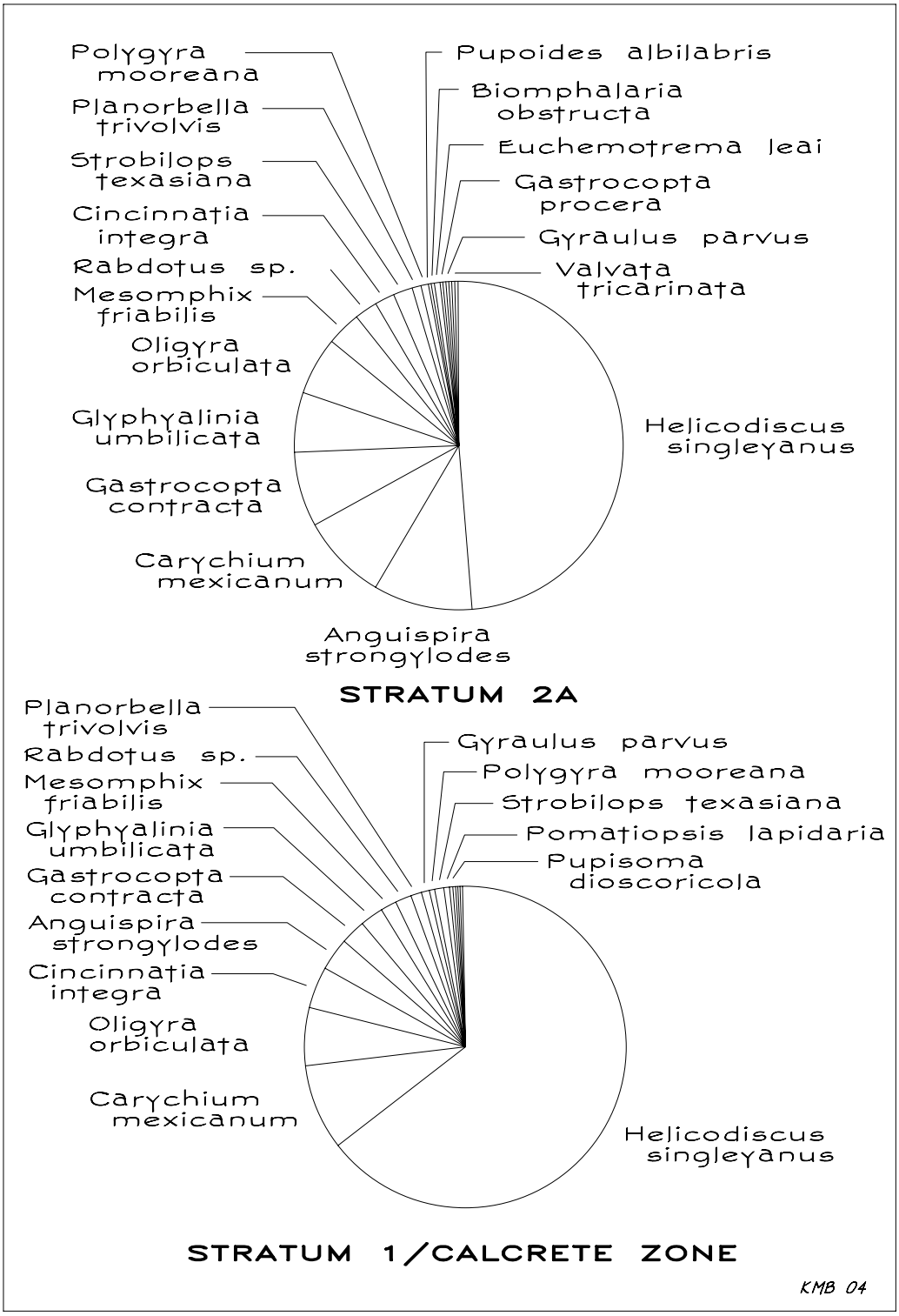

Figure 8.87. Taxonomic Composition of Matrix Columns, Strata 1 and 2A.

Cluster Analysis of the Matrix Columns

Combining the results for the N109 E103 and N110 E102 matrix columns produced a simplified data matrix consisting of 25 variables (taxa) and 47 cases (matrix samples). The raw specimen counts were used, not converted to percentages or weighted by sample volume. All the aquatic species were combined into a single "aquatic" variable, and both species of *Polygyra* were combined into a single "Polygyra" variable for this analysis. Clustering of excavation levels (Fig. 8.88) shows considerable stratigraphic coherency, as was the case when the 1/4-inch samples were clustered. Clustering of species largely groups them by abundance (Fig. 8.89), replicating the ranking seen in the pie chart (Fig. 8.84). *Helicodiscus singleyanus* and *Oligyra orbiculata* appear as outliers, followed by *Anguispira strongylodes* and a cluster composed of *Carychium mexicanum* and *Gastrocopta contracta*. This is essentially an ordering based on numerical abundance.

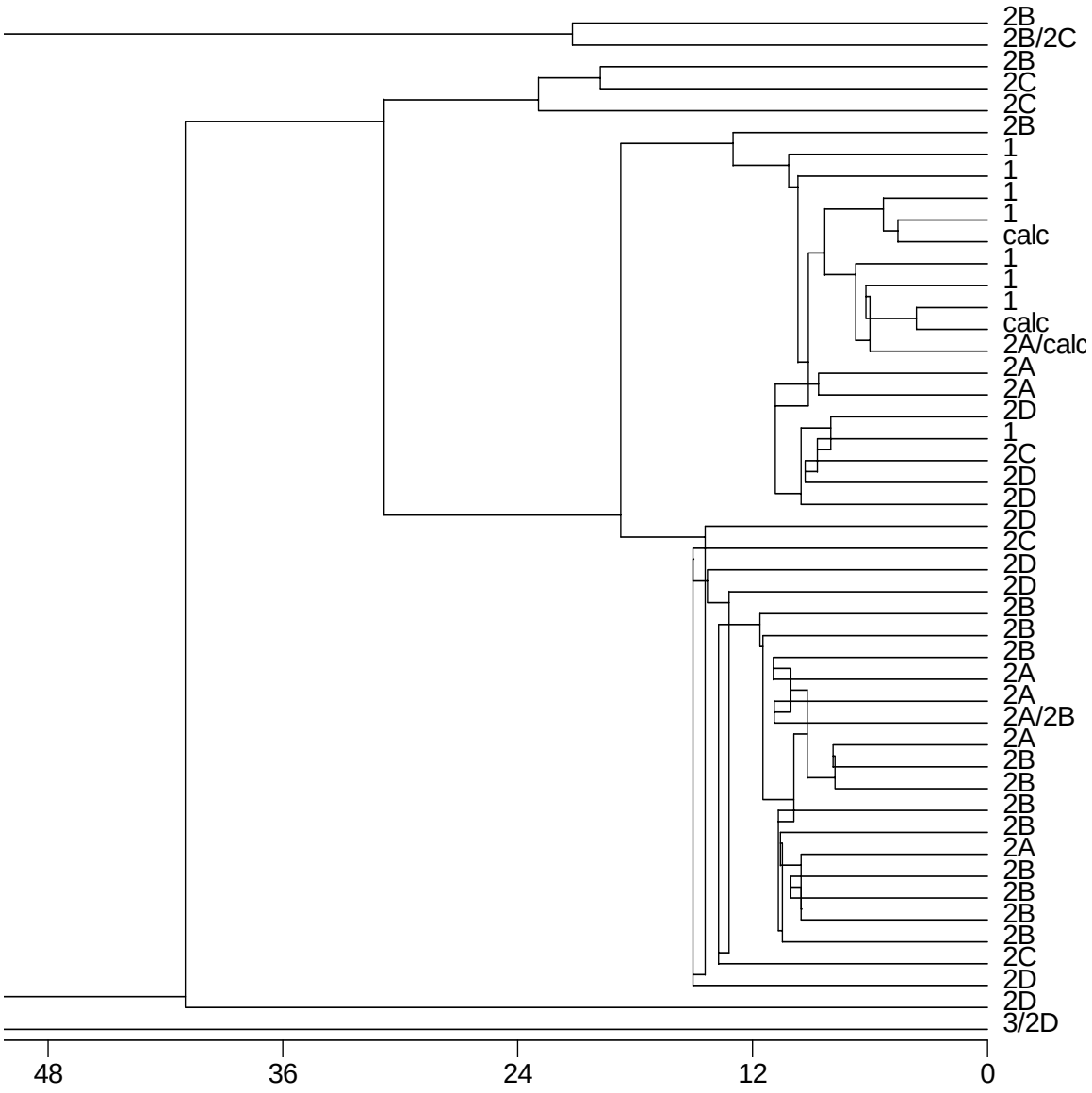

Figure 8.88. Cluster Analysis of Snails From Combined Matrix Columns. Clustering by variables using the centroid method and a Euclidian distance function (scale at bottom). MVSP 3.1 analysis uses 25 variables (taxa) and 47 cases (matrix samples). All aquatic snails were combined for this analysis, and both species of *Polygyra* were also combined. Note strata tend to cluster together to a large extent.

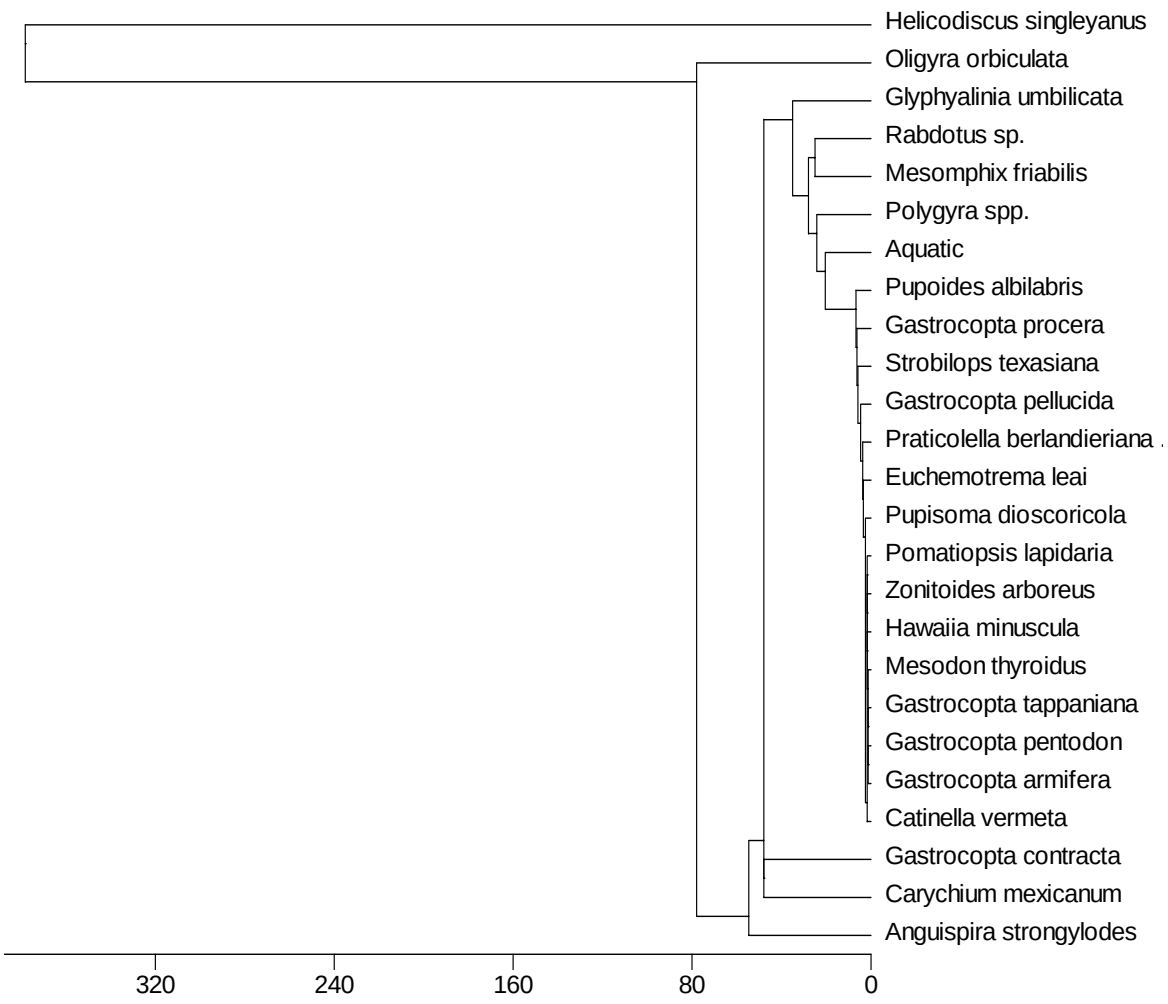

Figure 8.89. Cluster Analysis of Snails From Combined Matrix Columns. Clustering by cases using the centroid method and a Euclidian distance function (scale at bottom). MVSP 3.1 analysis uses 25 variables (taxa) and 47 cases (matrix samples). All aquatic snails were combined for this analysis, and both species of *Polygyra* were also combined.

Correspondence Analysis of the Matrix Columns

Correspondence analysis was done using the same 25 species by 47 sample data matrix used for the cluster analysis. This analysis uses more variables and fewer cases than the correspondence analysis done on the 1/4-inch screen sample, but has similar resolving power. The first three axes extracted explain about 52% of the variance in the matrix. Detrending and downweighting were not used. Table 8.30 shows variable scores for the first three axes

The principal difference between this correspondence analysis and the one done for the 1/4-inch screen sample is that the first two axes are reversed. That is, the first axis appears to reflect aridity or drought resistance, and the second axis is identified with aquatic and riparian woodland species, while for the 1/4-inch screen sample, the first axis was identified with aquatic and riparian woodland species, and the second axis with dry woodland. This difference is probably due to the large numbers of moisture-sensitive microsnails in the sieved matrix samples. The first three axes from the correspondence analysis of the matrix samples are interpreted as follows:

Axis 1: dry woodland

High positive loadings

Gastrocopta pellucida (well drained, open)	3.523
Mesodon thyroidus (dry woodland)	3.347
Polygyra spp. (woodland)	2.272
Rabdotus sp. (well drained, open)	2.044
Euchemotrema leai (woodland)*	1.875
Oligyra orbiculata (open, drought-resistant)	1.874

High negative loadings

Pomatiopsis lapidaria (amphibious)	-2.391

Pupisoma dioscoricola (wet floodplain)	-1.759
Carychium mexicanum (wet floodplain)	-1.580

Axis 2: aquatic and deciduous woodland taxa

High positive loadings

Pupisoma dioscoricola (wet floodplain)	5.591
Aquatic species, combined	5.340
Pomatiopsis lapidaria (amphibious)	4.880
Strobilops texasiana (woodland)	1.901

High negative loadings

Zonitoides arboreus (open, dry woodland)	-3.428
Praticolella berlandieriana (open, dry woodland)	-3.037
Polygyra spp. (woodland)	-1.046
Oligyra orbiculata (open, drought-resistant)	-0.536

Axis 3: dry woodland? (interpretation uncertain)

High positive loadings

Mesodon thyroidus (dry woodland)	4.902
Zonitoides arboreus (open, dry woodland)	3.782
Pupisoma dioscoricola (wet floodplain)*	2.185
Polygyra spp. (woodland)	2.110

High negative loadings

Gastrocopta tappaniana (wet floodplain)	-5.594
Euchemotrema leai (woodland)	-2.707
Gastrocopta contracta (mesic floodplain)	-2.127

* This species seems incompatible with the others in this group.

Axis 1 (31% of variance) has positive loadings chiefly for species that are fairly drought-resistant and adapted to well-drained terrain ranging from open and grassy to partly wooded. Marshy and mesic riparian floodplain species show negative loadings.

Axis 2 (12% of variance) has positive loadings for marshy and wet floodplain species and negative loadings for some of the drought-adapted species. This is a “mesic” axis.

Axis 3 (less than 9% of variance) is less interpretable, but seems to be another xeric axis. Positive loadings are mostly for dry woodland species, but *Pupisoma dioscoricola* is inexplicably grouped with this axis, and aquatic snails also have a fairly high positive loading. This axis seems to be less xeric and more mesic than axis 1.

Figure 8.90 is a bi-axis plot for the first two axes from the matrix sample correspondence analysis; Figure 8.91 shows axes 1 and 3. In both these plots, which show the individual samples marked by their stratum assignments, the horizontal axis is characterized by increasing aridity toward the right side. Most of the stratum 1 samples cluster toward the left side, and most of the stratum 2D samples toward the right side, because there is a moderate long-term trend toward increasing aridity toward the top of the bench stratigraphic section. Clustering is particularly well-defined in Figure 8.91.

Figure 8.92 is a bi-axis plot of the variables (taxa) from correspondence analysis of the combined matrix samples. The different species are distributed on this plot largely in terms of moisture sensitivity. Species in the upper lefthand quadrant (such as *Pomatiopsis lapidaria*, *Pupisoma dioscoricola*, and the aquatic species) have the highest moisture requirements, while species at the right end of axis 1 (such *as Gastrocopta pellucida*, *Oligyra orbiculata*, and *Polygyra* spp.) are the most drought-adapted. *Mesodon thyroidus* and *Catinella vermeta* appear much farther toward the xeric end of axis 1 than

expected (although *Catinella* often thrives in damp microhabitats that are embedded in much drier environments).

Figures 8.93 and 8.94 are vertical plots of case scores on the first three axes for the N109 E103 and N110 E102 matrix sample columns, respectively. Figure 8.93 shows the clearest vertical pattern. The scores for axis 1, identified with dry woodland species, increase upward in the stratigraphic column, especially above 92.50 m, indicating increasing aridity late in the stratigraphic sequence. The increase begins near the top of stratum 2B and continues through strata 2C and 2D, with a brief regression in stratum 2D. The vertical plot for the N110 E102 column (Fig. 8.94) is almost identical. It begins at the base with a great deal of variability in all axes in stratum 1, then shows the same pattern of upward increase above that. The strongest peaks for mesic-adapted species (axis 2) occur at the top of stratum 1 and near the base of stratum 2B.

Table 8.30. Correspondence Analysis of Snail Taxa From Combined Matrix Samples.

	Axis 1	Axis 2	Axis 3
Eigenvalues	0.159	0.063	0.044
Percentage	31.38	12.31	8.70
Cumulative Percentage	31.38	43.68	52.38

Variable scores	Axis 1	Axis 2	Axis 3
Anguispira strongylodes	0.609	1.378	-0.738
Carychium mexicanum	-1.580	-0.622	-1.405
Catinella vermeta	0.738	0.606	1.367
Euchemotrema leai aliciae	1.875	0.195	-2.707
Gastrocopta armifera	-1.564	-2.522	1.829
Gastrocopta contracta	-0.261	0.026	-2.127
Gastrocopta pellucida	3.523	0.765	-2.450
Gastrocopta pentodon	-2.189	-4.215	-1.816
Gastrocopta procera	0.581	1.253	1.399
Gastrocopta tappaniana	-2.019	-0.664	-5.594
Glyphyalinia umbilicata	-0.203	-0.130	-0.373
Hawaiia minuscula	0.510	-1.767	-0.258
Helicodiscus singleyanus	-0.450	-0.286	0.584
Mesodon thyroidus	3.347	-0.741	4.902
Mesomphix friabilis	1.378	0.586	-1.643
Oligyra orbiculata	1.874	-0.536	-0.094
Polygyra sp.	2.272	-1.046	2.110
Pomatiopsis lapidaria	-2.391	4.880	0.582
Praticolella berlandieriana	0.364	-3.037	-0.010
Pupisoma dioscoricola	-1.759	5.591	2.185
Pupoides albilabris	1.146	0.353	0.503
Rabdotus sp.	2.044	0.304	-0.087
Strobilops texasiana	-0.514	1.901	-0.823
Zonitoides arboreus	1.242	-3.428	3.782
Aquatic species, combined	-0.734	5.340	1.569

Notes: no detrending, no downweighting of rare taxa, maximum of five axes; 25 variables (taxa), 47 cases (matrix samples). Analysis is for combined matrix samples from N109 E103 and N110 E102.

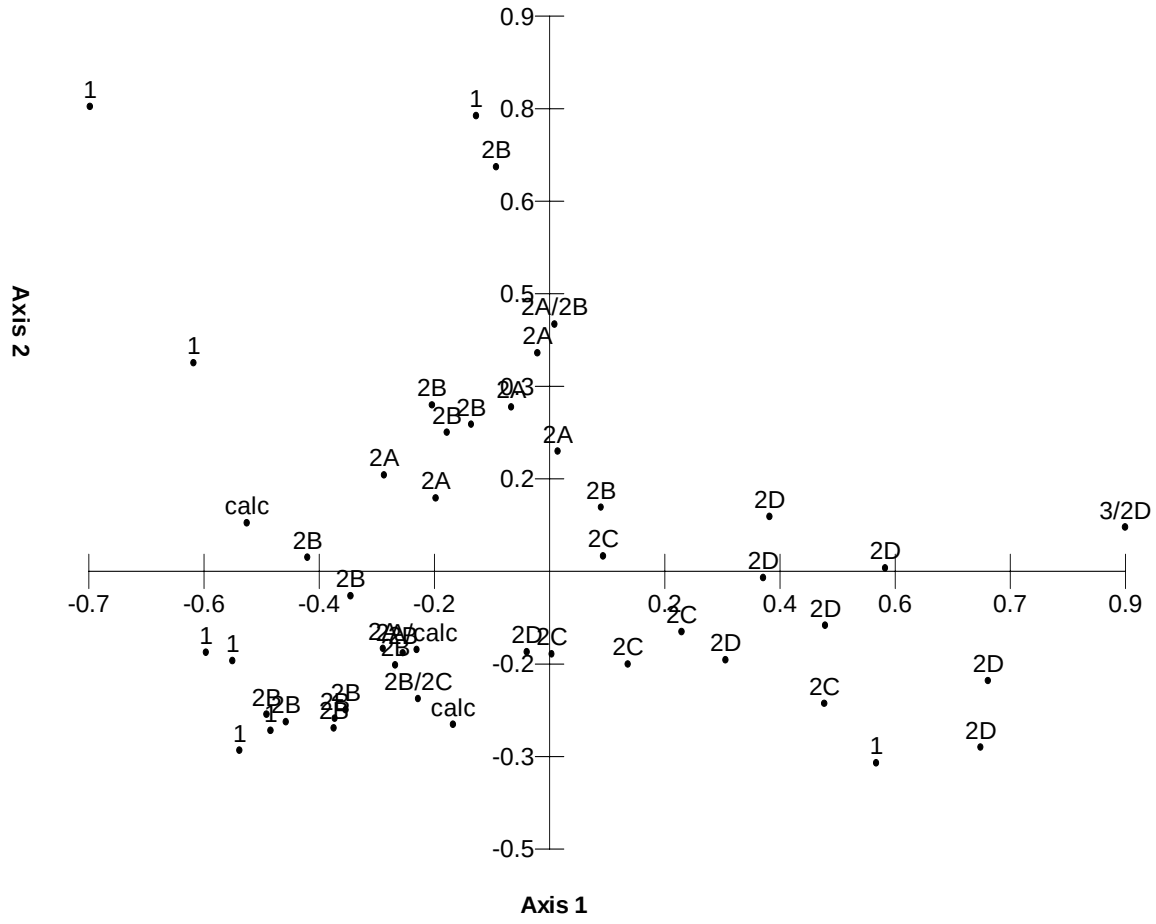

Figure 8.90. Correspondence Analysis of Snails From Combined Matrix Columns. Plot of cases (excavation levels identified by stratum) on the first two axes. This analysis uses the simplified matrix (aquatic species combined, *Polygyra* species combined), no detrending, and no downweighting of rare species. The first axis appears to record increasing aridity from left to right.

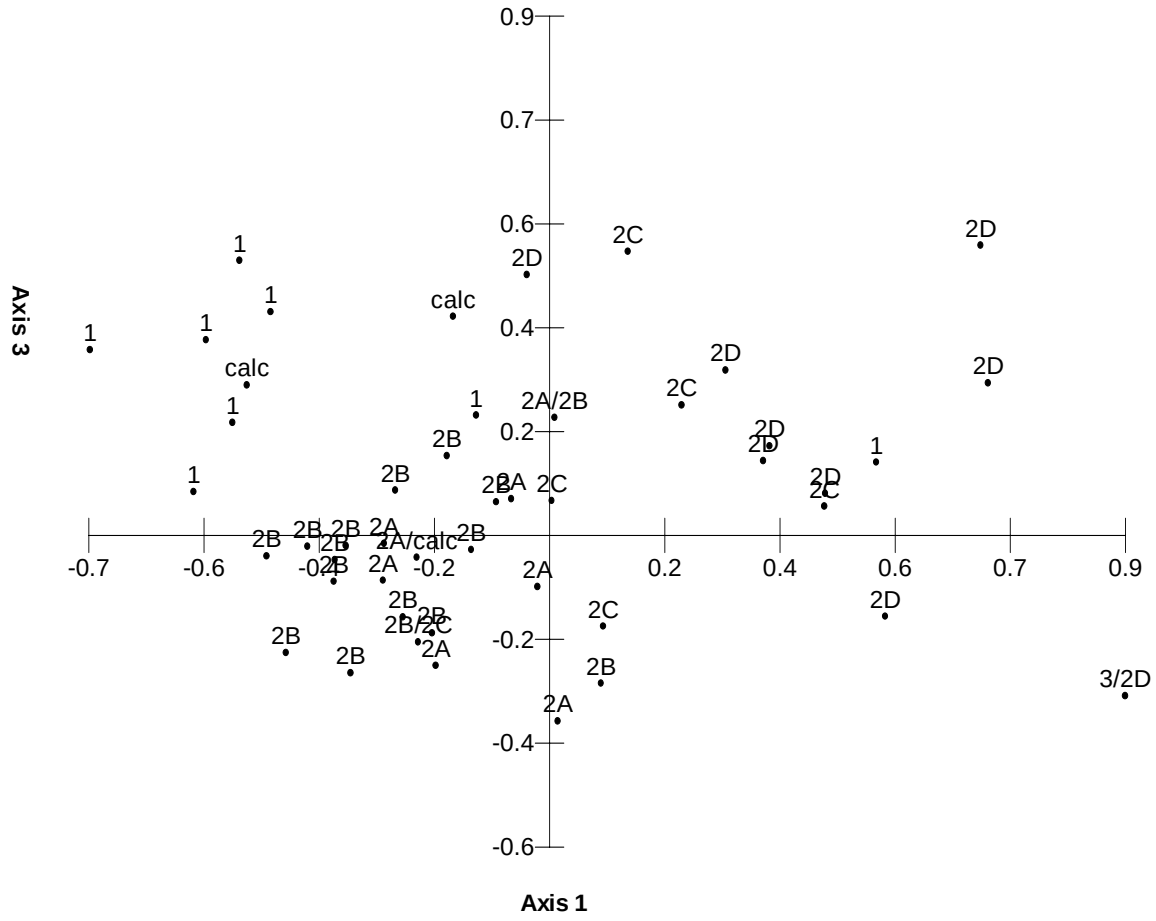

Figure 8.91. Correspondence Analysis of Snails From Combined Matrix Columns. Plot of cases (excavation levels identified by stratum) on the first and third axes. Note clustering of stratum 1 samples in upper left quadrant and stratum 2D samples in right-hand quadrants.

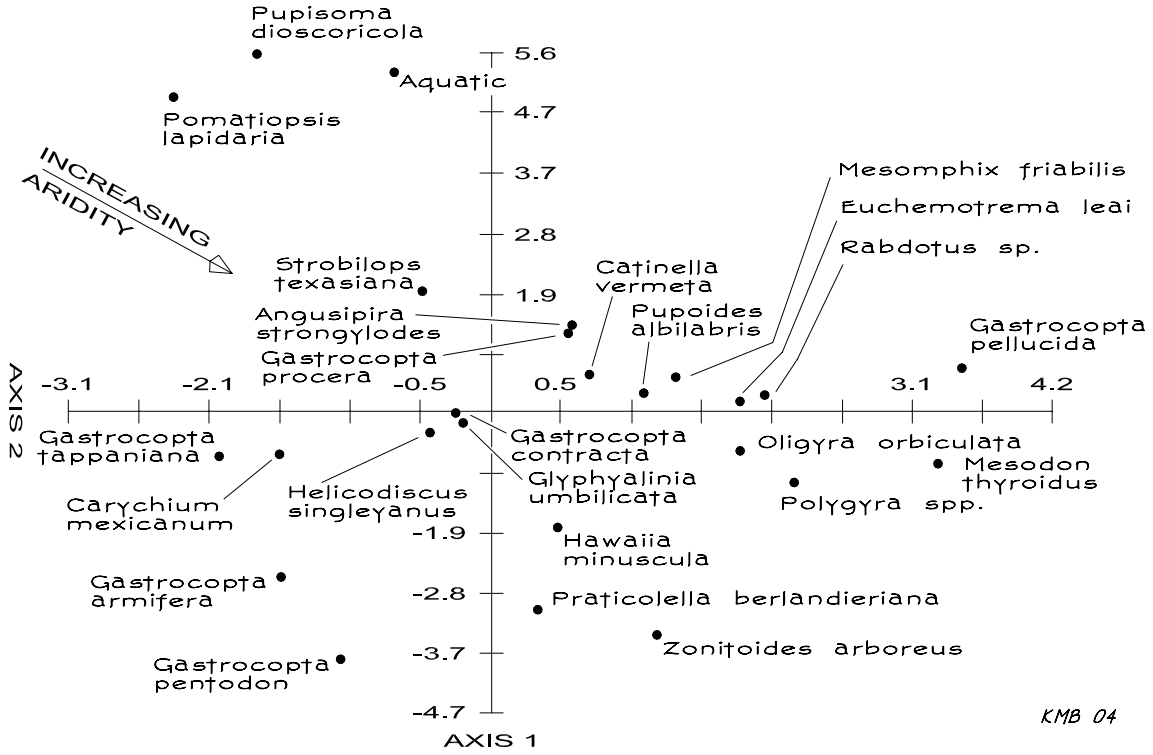

Figure 8.92. Correspondence Analysis of Snails From Combined Matrix Columns. Plot of variables (taxa) on the first two axes. The species are arranged mostly along a moisture gradient decreasing from upper left to lower right.

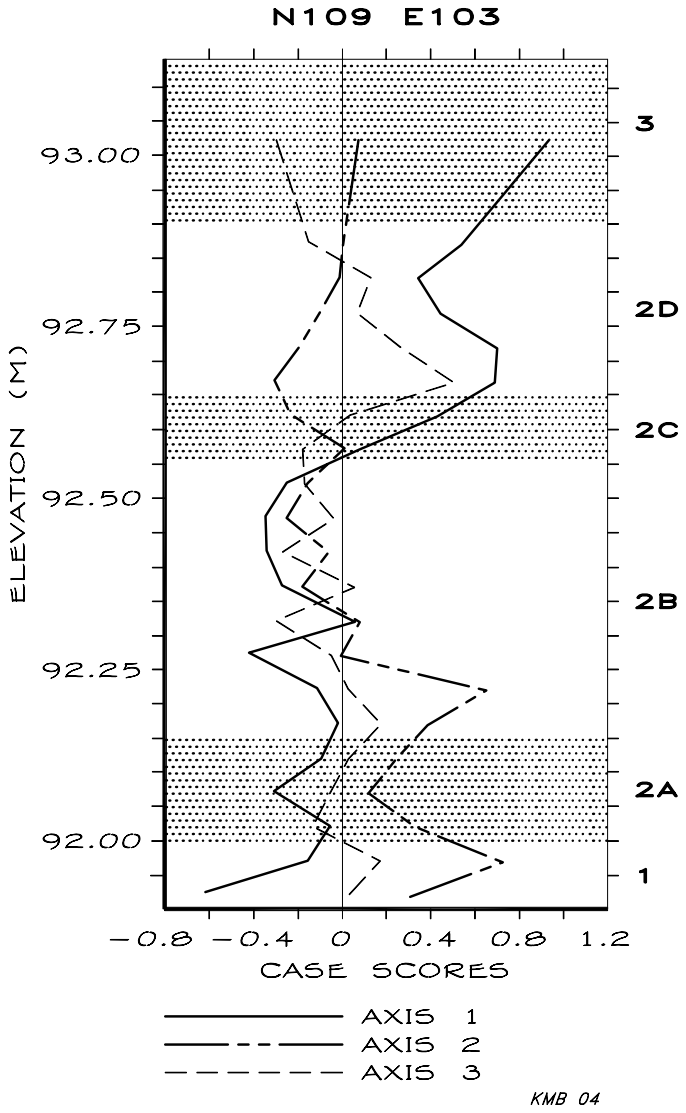

Figure 8.93. Vertical Plot of First Three Axes, N109 E103. Case scores from correspondence analysis of snails from sieved matrix samples are shown. Note axis 1 (dry woodland taxa) tends to increase upward, and peaks in scores do not coincide with strata.

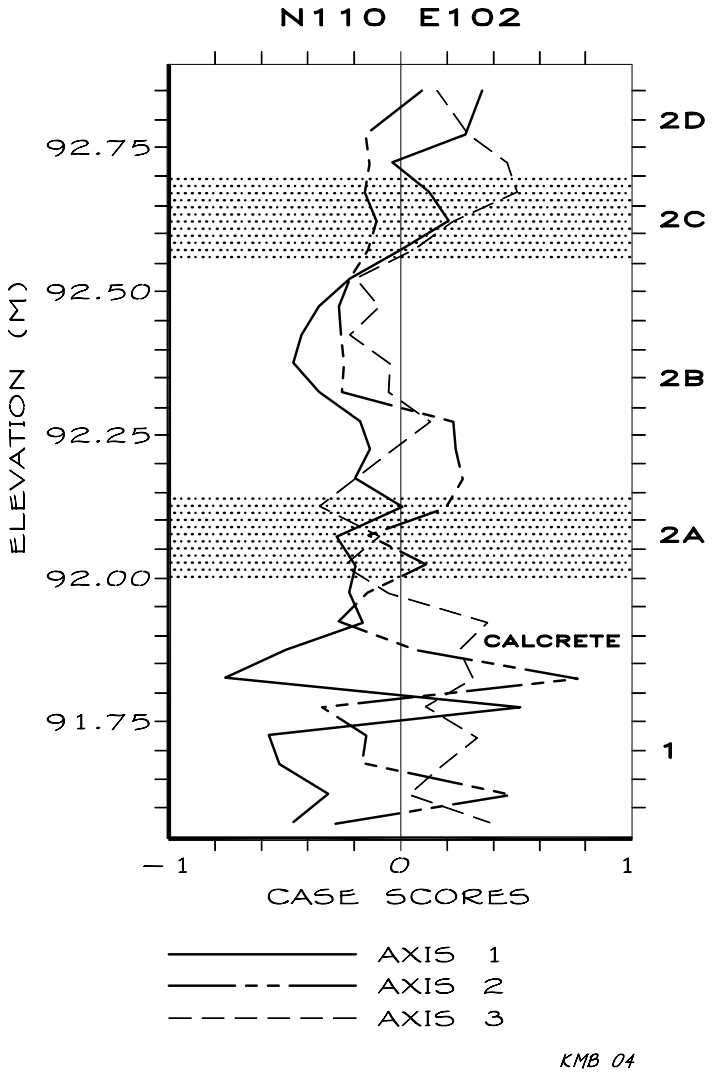

Figure 8.94. Vertical Plot of First Three Axes, N110 E102. Case scores from correspondence analysis of snails from sieved matrix samples are shown. All three axes are highly variable in stratum 1. The vertical patterns here are very similar to the previous plot.

SUMMARY AND CONCLUSIONS FOR CHAPTER 8

Composition of the Fauna

The Late Pleistocene-early Holocene snail fauna found in the bench deposits at Berger Bluff is species-rich (biologists apply the term “speciose”). As far as can be determined, there are at least 35 or 36 species present. The exact number is uncertain because of uncertainty about some of the classifications (particularly *Rabdotus*, or species like *Polygyra mooreana* or *Praticolella berlandieriana* that were identified by Raymond Neck, but which I suspect are not applicable). Further picking and sorting of matrix from N109 E96 might also reveal additional species. Table 8.31 records species richness for some contemporary snail surveys and some archeological sites where fine-mesh sampling has been done. Berger Bluff is second only to Lubbock Lake in species richness.

Microsnails, medium-sized, and large snails each represent about a third of the Berger Bluff species list. From this inventory, 25 or 26 are terrestrial snails that fall into two major groupings: 10 species that are chiefly cosmopolitan, eurytopic, drought-tolerant species well adapted to stressful habitats; and another 15 or 16 species that are chiefly woodland snails, many of them found in mature, deciduous floodplain woodlands. Included in this group is at least one unidentified species of slug. As in most biological assemblages, most of the species are represented by relatively few individuals, but two species from the eurytopic, drought-tolerant group (*Helicodiscus singleyanus* and *Oligyra orbiculata*) are numerically dominant in the fine-sieved samples, where they represent over 60% of the individuals.

Table 8.31. Snail Species Richness at Some Southern Plains Sites.

Locality	Number of taxonomic categories*
Contemporary surveys	
Welder Refuge (Branson 1960)	33
Preiss Ranch drift sample (Table 8.8)	27
Goliad State Park (Neck 1977)	22
Sleeper site vicinity (Neck 1991)	18
Southern Plains Gastropod Survey	2-14**
Smyth Crossing (Table 8.4)	10
Victoria (Neck 1977)	6
Archeological or paleontological studies	
Lubbock Lake (Pierce 1987)	47
Berger Bluff bench	35-36
Wilson-Leonard (Shaw *et al*. 1998)	35
Aubrey pond margin (Neck 2001)	33
Aubrey pond axis (Neck 2001)	32
Lake Theo (Neck 1987a)	28
Domebo (Cheatum and Allen 1966)	28
Burnham (Theler 2003a)	26
Mustang Branch (Neck 1994b)	21
Hajny Mammoth fifth spring (Theler 1992)	19 or more
Hajny Mammoth second spring (Branson 1992)	15
Richard Beene (Neck 1992)	16
Sleeper (Neck 1991)	13
Winston's Cave (Hudler 2000)	12
Buckhollow (Neck 1994c)	10

* "Taxonomic categories" are mostly species, but may include higher order groupings or morphological categories.

** Anywhere from two to 14 taxa were found at a single collecting locality; 24 taxa were found in the entire survey.

In addition to the terrestrial species, there are two species of amphibious snails and at least eight species of aquatic snails. In general, these are much less numerous than the terrestrial snails. In the matrix columns, terrestrial snails represent 97.8% of all individuals, amphibious snails account for 0.20%, and aquatic snails account for 2%. This kind of assemblage is characteristic of an elevated floodplain or terrace without major depressions, oxbows, or ponded water. For large and medium-bodied snails recovered from the 1/4-inch screen, 99.5% are terrestrial and 0.5% are aquatic (the only amphibious species from the 1/4-inch screen are tabulated as fortuitously recovered microsnails here).

Archeological sites with major swales, cienegas, ponds, or oxbow lakes may yield significant numbers of stagnant water aquatic snails (*Planorbella*, *Gyraulus*, *Biomphalaria*, *Physella*, *Micromenetus*, etc.) and amphibious snails (*Oxyloma*, *Succinea*, *Catinella*, etc.). Recognizable assemblages of snails from damp habitats are referred to as *wet ground taxocenes* (that is, similar assemblages occur at multiple sites; Evans *et al*. 1992; Davies, Gale and Lees 1996; Davies 1998).

Several southern Plains sites have yielded candidates for wet ground taxocenes. At Lubbock Lake, the major lacustrine or marsh units are strata 2, 3 and 4B. These units yielded amphibious taxa such as *Oxyloma* and *Succinea*, many aquatic taxa such as *Gyraulus parvus, G. circumstriatus*, *Physa anatina, P. gyrina*, *Lymnaea palustris*, and *L. humilis*, as well as a few terrestrial taxa (*Gastrocopta pentodon*, *Vertigo ovata* and, curiously, *Hawaiia minuscula*; Pierce 1987:Tables 6.1, 6.2). Roughly 97% of the individuals are aquatic. At the Aubrey site, the pond margin yielded large numbers of the amphibious snail *Pomatiopsis lapidaria*, smaller numbers of *Catinella avara*, and much smaller numbers of aquatic species such as *Gyraulus parvus* or terrestrial species such as

Gastrocopta contracta, *Strobilops texasiana*, and *Discus cronkhitei* (Neck 2001:Table 7.2). Of the pond margin individuals, 6% are aquatic (9 taxa), 73% are amphibious (4 taxa), and 21% are terrestrial (19 taxa). At the Burnham site in Oklahoma, the North 3 Trench sampled a pond or pond margin (Theler 2003a:173). Here 65% of the individuals are terrestrial (about 16 taxa), 3% are amphibious (one taxon), and 32% are aquatic (about a dozen taxa; Theler 2003a:Table 11.3).

These three sites vary widely in the relative proportions of terrestrial, amphibious and aquatic species, but it is clear that none of them are dominated by terrestrial species to the extent that the bench deposits at Berger Bluff are. If the proportions can be used as a guide, the floodplain sediments at Berger Bluff were better drained and less subject to flooding than the sampled areas of Lubbock Lake, the Aubrey site, and the Burnham site. If the sampled areas of the bench sediments had been boggy or marshy, they probably would have yielded large numbers of *Succinea*, *Oxyloma*, *Catinella*, *Pomatiopsis*, or similar species, although these species are also quite fragile and subject to taphonomic deletion.

Although studies of the snails from the bench deposits seem to indicate somewhat drier conditions than suggested by the sediment and diatom studies, nevertheless there is evidence of greater effective moisture and greater species richness in the Younger Dryas and early Holocene than at present, as is the case at Lubbock Lake, the Aubrey site, and the Richard Beene site.

Extirpations and Range Changes

Unlike the mammal fauna, there were few actual extinctions among the North American gastropod fauna at the end of the Pleistocene (the giant slug, *Deroceras aenigma*, is one of the few exceptions), and there are no extinct species in the bench fauna. However, several major geographic range shifts were begun at the onset of the Holocene, and in fact essentially the entire fauna is still making gradual adjustments to climatic change today. Most of these changes are eastward or northeastward contractions of range in response to Holocene drying, but in a few cases, neotropical species have expanded northward from Mexico or westward along the Gulf coast during the Holocene. In cases where a species has withdrawn entirely from the state of Texas, the term "extirpation" can be applied, but extirpation is really just a more extreme case of range contraction. At Berger Bluff, the most significant examples are prosobranch aquatic or amphibious species.

The chief effect of these Holocene range changes at any particular location is the deletion from the species list of several species that were present in the Pleistocene and the addition of a few new tropical species arriving from the south or the Gulf region. Neck (1995a) estimates that Quaternary fossil snail assemblages from the southern Plains, with over 140 species, have been reduced to just over 40 species at present, and only part of the discrepancy is due to time-averaging of the fossil faunas. He attributes the depauperization of the fauna to regional drying, increased thermal stress, and increased seasonality.

The most significant extirpation in the snail fauna from the bench sediments is *Valvata tricarinata*, an aquatic snail with northern affinities usually found in cold lakes and rivers or, in the southern part of its range, in cold springs or ponds. It is a common Pleistocene index fossil. Contemporary populations are found no farther south than Nebraska (or possibly western Oklahoma or Arkansas? Fig. 8.95), where Taylor (1960) found it in water at 15° C (59° F). A reported occurrence in New York at 24° C (75° F) is probably atypically warm. The species has been entirely extirpated from Texas and much of the southern US as a result of Holocene warming and drying. Specimens from the bench are well-preserved and similar in condition to other kinds of snails, and there are no indications they have been redeposited from older Pleistocene deposits.

A second aquatic species, *Cincinnatia integra*, is more problematical. Fullington (1978) listed it as "fossil, potentially recent," but sparse populations apparently are scattered across Texas, including the lower Guadalupe River drainage. Seven specimens were found in the Preiss Ranch drift sample. This is probably a species that has been reduced in numbers but not entirely extirpated during the Holocene. Both of these aquatic species are prosobranch (gill-breathing) snails.

Pomatiopsis lapidaria, an amphibious marsh snail, is another prosobranch snail now extirpated in Texas (Fig. 8.7). It appears at the Aubrey, Domebo, and Wilson-Leonard sites and is probably another Pleistocene index species, found at sites with cienega deposits.

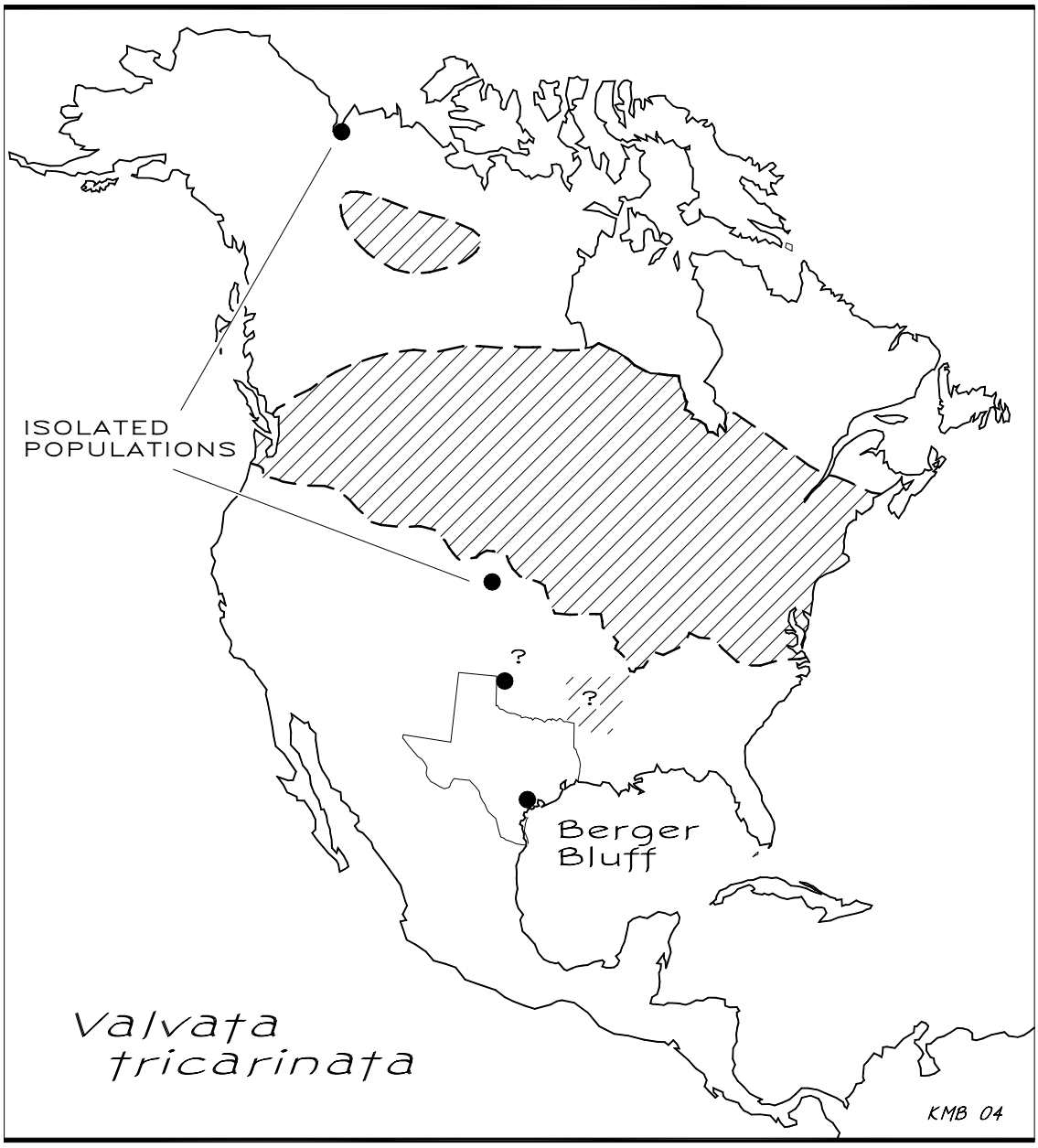

Figure 8.95. Contemporary Range of *Valvata tricarinata*. Approximate distribution based on La Rocque (1968:Fig. 221), Clarke (1973:238), Burch and Tottenham (1980:84). Question marks designate doubtful occurrences.

A single example of *Gastrocopta tappaniana* was found in the bench deposits. Although a few specimens are occasionally found in archeological or paleontological sites, Cheatum and Fullington (1973) report finding no living populations in Texas. Neck (1994e:147) reports it in Travis County, so perhaps it exists now only in protected refugia. A wet floodplain dweller, like *Pupisoma dioscoricola*, it may be found on the undersides of palmetto leaves.

A single *Gastrocopta armifera* was also found. This terrestrial microsnail is found today mostly west of the Balcones Escarpment and appears to be absent from the Gulf Coastal Plain. Its appearance at Berger Bluff is probably a rare example of westward range contraction during the Holocene. According to Raymond Neck (personal communication), this is the first find of this species on the Gulf Coastal Plain.

I have also tentatively identified one other terrestrial species now characteristically found on the Edwards Plateau. A single specimen thought to be *Glyphyalinia roemeri* was found in the bench deposits. Eight specimens thought to be *Mesodon roemeri* were found in the bench deposits. This species has been reported from Goliad State Park (Table 8.5) but is otherwise probably rare in the region at present. If these identifications are correction, they may be evidence of westward and/or northward range contractions during the Holocene.

Comparisons With Contemporary Faunas

Although contemporary snail faunas in and near the Coleto Creek basin are not very well documented, there are major differences between the known species lists and the Younger Dryas-early Holocene assemblage recovered from the bench deposits.

Contrasting the modern species lists and counts shown in tables 8.5 through 8.9 with the lists and counts recovered from the bench deposits (shown in tables 8.11, 8.20-8.25 and 8.28-8.29) highlights these differences.

Several genera or species appear in the Preiss Ranch drift sample that are absent from the bench deposits. Five terrestrial species [*Euconulus* sp., *Helicodiscus eigenmanni*, *Polygyra auriformis, P. cereolus*, *Vertigo rugulosa* (?)] and at least one aquatic species [*Micromenetus dilatatus* (?) and possibly some species of *Drepanotrema*] appear to be new additions to the fauna. *Thysanophora hornii* is also reported from Goliad State Park (Table 8.5). These new additions are a mixture of central Texas, east-central Texas, Gulf Coastal Plain, tropical and arid-adapted species.

Several species present in the bench deposits seem to be absent or rare in the contemporary fauna. Two terrestrial species (*Gastrocopta armifera* and *Glyphyalinia* cf. *G. roemeri*) appear to be present there but absent in the modern fauna. Four more species (*Euchemotrema leai*, *Hawaiia minuscula*, *Mesodon roemeri*, and an unidentified slug) are present in the bench deposits but are either rare or have simply been overlooked in the modern fauna. One amphibious species (*Pomatiopsis lapidaria*) and one aquatic species (*Valvata tricarinata*) found in the bench are known to have been regionally extirpated. One lymnaeid snail (cf. *Fossaria* sp.) recovered from the bench may or may not be present in the modern fauna.

Some of the most important shifts in the snail fauna are ones of degree rather than kind. The most dramatic example is the substantial replacement of *Gastrocopta contracta*, a mesic-adapted species found in abundance in the bench deposits, with

Gastrocopta pellucida, a drought-adapted species found in abundance in the modern fauna (Table 8.13). In the bench deposits, *Gastrocopta contracta* accounts for about 89% of all *Gastrocopta* individuals, *Gastrocopta pellucida* for about 3%. In the diatom sampling quadrats on the Preiss Ranch (Table 8.7), *Gastrocopta contracta* accounts for about 6% of all identifiable *Gastrocopta* individuals, *Gastrocopta pellucida* for about 94%. In the drift sample, *Gastrocopta contracta* accounts for about 28% of all identifiable *Gastrocopta* individuals, *Gastrocopta pellucida* for over 59% (Table 8.8). This is one of the clearest examples of partial species replacement driven by increased aridity and continentality of climate during the Holocene.

Another example is the Holocene population explosion of *Oligyra orbiculata*. This highly adaptable, drought and stress-resistant operculate species is probably the most abundant and widespread medium or large-bodied snail across most of the state of Texas today. In the sieved matrix columns from the bench, it represents less than 9% of the count for all species. This is probably the most representative recovery method. In the 1/4-inch screen sample, which fails to capture juveniles and small adults (as well as microsnails), *Oligyra* represents about 46% of the medium and large-bodied species. At the Smith Creek Bridge site, it represents about 58% of the sample, and increases dramatically in frequency over time (Brown 2002:263-264). I attribute this explosion in population size to its ability to out-compete less adaptable species in the increasingly continental climates of the Holocene, and I suspect the beginnings of this population increase can be seen in the increased percentages of *Oligyra* that appear in strata 2D and 3 at the top of the bench deposits.

Some species common to abundant in the bench deposits are reported still present in the area, but seem to be rather rare in the modern fauna of the catchment. *Anguispira strongylodes*, *Mesomphix friabilis*, *Cincinnatia integra*, and possibly *Euchemotrema leai* are examples. These large to medium-bodied woodland snails, *Anguispira*, *Mesomphix*, and *Euchemotrema*, are present in the upper deposits at Berger Bluff, but absent at the Smith Creek Bridge site (only two *Euchemotrema* specimens were found), and only one example of the aquatic snail *Cincinnatia* was found at that site.

In general, most of the species that have been deleted or at least reduced in the Holocene local fauna are moisture-dependant or dependant on the presence of mature, riparian deciduous woodland while the species that are new additions or have increased in density are cosmopolitan and drought-resistant, able to thrive in less heavily vegetated habitats.

Stratigraphic Trends and Ordination Results

Numerical studies of the matrix and 1/4-inch screen samples make it clear that there is moderate spatial patterning of snails in the bench deposits. That is, the snails are neither strongly patterned nor randomly distributed in the deposits. The first three axes in the correspondence analyses account for about 50% of the variance in the data matrix. This suggests there were no radical changes in habitat during the Younger Dryas and early Holocene period represented by the bench deposits.

Nevertheless, there are clear indications of progressive drying during this time. This can perhaps be seen most easily in Figure 8.93 and 8.94, where the axis 1 (dry

woodland) case scores drift toward the right side of the graph as they climb upward; or in Figure 8.82 and 8.83 where the axis 1 (aquatic and deciduous woodland) case scores drift to the left as they climb upward. It can also be seen in the bi-axis plots, especially Fig. 8.91, where most of the stratum 1 samples are clustered at the left (mesic or negative) end of axis 1 and most of the stratum 2D samples are clustered at the right (xeric or positive end). The same trend can also be discerned in the various pie charts presented in this chapter (Figs. 8.26, 8.76-8.78, 8.85-8.87) in which woodland species like *Anguispira strongylodes* or *Carychium mexicanum* become less abundant through time and cosmopolitan, drought-resistant species like *Oligyra orbiculata* become more abundant late in the sequence (Fig. 8.46). This is a long-term trend that persists throughout the stratigraphic section and crosscuts strata. Aquatic snails are also less common later in the sequence, although this could be due to increasing elevation of the floodplain surface above the channel bed. The ordination studies seem to arrange the species chiefly along a gradient of varying moisture dependence. None of the numerical studies seem to sort them out by body size, shell robustness, or other characteristics.

In Chapter 4, I asked whether the alternating sandy and muddy strata making up the bench deposits should be considered the result of regional climate variation or the autochthonous result of localized channel shifting. I suggested that the ecological signature of organisms preserved in the strata might help to clarify that question. Where the snail fauna is concerned, the sandy and muddy units do not seem to have an ecological signature. Adjacent strata are more similar than different (Fig. 8.89), and the significant trends that can be discerned tend to crosscut strata rather than to link them in groups.

SUMMARY OF CHAPTER 8

The bench deposits hold the remains of a diverse snail fauna, a fauna adapted to somewhat greater effective moisture (and probably lower air and water temperatures) than at present. Many of the species are saprophilous leaf litter dwellers indicating the presence of a mature, riparian deciduous woodland covering the floodplain and perhaps the adjacent valley slopes. This is a mesic to dry woodland fauna, but not a wet ground taxocene like those seen in Pleistocene cienega deposits in the desert west. Hydrological changes at the end of the Younger Dryas probably stripped out much of this riparian woodland and the snail populations that lived in the leaf litter, perhaps replacing slow-growing broad-leafed tree species with faster-growing species adapted to more frequent and peaked flood events. Regional changes in climate and environment reduced snail species diversity, causing statewide extirpations of some species (mostly gill-breathing aquatic or amphibious species) and significant geographic range changes for others. *Valvata tricarinata*, a Pleistocene marker species, is the most notable of these deleted taxa Typically a lake or cold spring snail, it was probably extirpated when groundwater temperatures rose at the end of the Younger Dryas. New eurytopic species, more cosmopolitan and drought–resistant than the deleted stenotopic species, entered from the south or east to replace the lost taxa. Elements of the Pleistocene fauna (for example, *Oligyra*, *Rabdotus*, and *Gastrocopta pellucida*) that were better adapted to the drier and more continental climates of the Holocene tended to increase in proportional representation through time.

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Chapter 9: Freshwater Mussels and Miscellaneous Invertebrates

INTRODUCTION

This chapter describes freshwater mussels (family Unionidae), sphaeriid clams and peaclams (both family Sphaeriidae), and a complete mud dauber nest recovered from the bench deposits. The mussels and the mud dauber nest are thought to be the result of human harvesting, while the sphaeriid clams and peaclams were probably deposited by flooding. I will also briefly review the freshwater mussels from the upper deposits, from contemporary populations in the Berger Bluff catchment, and from the archeological record in Texas and elsewhere. Only two species of freshwater mussels were found in the bench deposits proper: *Amblema plicata* (Threeridge, a moderate-sized collection) and *Megalonaias nervosa* (Giant Washboard, a single specimen), but a single example of *Quadrula apiculata* (Southern Mapleleaf) was found somewhat over 20 meters downstream from the excavation area, at about the same level as stratum 2A, and is also considered part of the bench mussel assemblage. It is outside the limits of the bench area, but inside the mapped extent of Berger Bluff as a whole. All three species are members of the subfamily Ambleminae. Because the size and age of the mussels may be related to the frequency and severity of catastrophic flooding, I will also discuss size and age estimates for *A. plicata*.

CONTEMPORARY MUSSEL POPULATIONS IN THE BERGER BLUFF CATCHMENT

Some of the earliest scientific research on freshwater mussels in Texas was done by Joseph D. Mitchell in the Victoria area and published in 1894. Probably collecting

from near the confluence with the Guadalupe River, Mitchell lists only four species from Coleto Creek: “Unio manubius” (now *Uniomerus declivis*), “Unio texasensis” (*Toxolasma texasensis*), “Unio berlandieri” (*Cyrtonaias tampicoensis*), and “Unio speciosus” (*Quadrula apiculata*; Mitchell n.d., 18-20). The only pelecypods reported from the Coleto Creek drainage during the pre-impoundment survey of aquatic ecology were five introduced Asian clams (*Corbicula* sp.) found at the Coletoville Road crossing (Murray, Jinnette, and Moseley 1976:Table 13). Asian clams were fairly abundant in the Coleto Creek bed sediments at Berger Bluff at the time of fieldwork

I also observed and collected flood-deposited shells at various locations in the Berger Bluff catchment while collecting soil and water samples for diatom analysis in 1997-98. In 2002, these were identified by Robert G. Howells, Heart of the Hills Research Station, Texas Parks and Wildlife Department. For location, see Brown (2002:Fig. 95). Mussels were collected from four diatom sampling localities, plus a stock pond near Berger Bluff examined during the Flume No. 3 survey in 1983.

Locality D-5: Salt Creek floodplain/channel, De Witt County; collected 10/2/97.

Toxolasma texasensis (right and partial left valve, male)

Locality D-6: Smith Creek, creek bed, De Witt County; collected 10/2/97.

Toxolasma texasensis (right valve, probable male)

Locality D-19: Smith Creek sandbar, De Witt Co.; collected 1/14/98.

Utterbackia imbecillis (1 left valve, 1 right valve fragment)

Toxolasma texasensis (fragments of 2 right valves)

Cyrtonaias tampicoensis (fragments of 2 left valves)

Lampsilis sp. (probably *L. hydiana*, less likely *L. bracteata*; left valve frag., male)

Ligumia subrostrata (1 left valve fragment, female)

Amblema plicata (1 disarticulated pair of valves, 1 right valve fragment)

Unidentified fragments

Preiss Ranch: Goliad County, locality D-20 upstream and downstream from confluence of Twelvemile Coleto and Fifteenmile Coleto Creek, following floods of 10/6-7/98, 10/18-20/98, and 11/13-15/98. Collected 11/18/98.

Lampsilis teres (1 disarticulated pair of valves, female; 1 pair of valves, not sexed; 8 right valves and fragments; 8 left valves and fragments)

Amblema plicata (2 left valve fragments; 4 right valve fragments, subfossil?)

Cyrtonaias tampicoensis (5 right valves and fragments; 8 left valves and fragments)

Lampsilis hydiana (left valve fragment, probably male)

Toxolasma texasensis (7 left valves and fragments; 3 right valves and fragments)

Unidentified fragments

Flume No. 3 Right-of-way: Goliad County, bank of upland stock tank on divide between Turkey Creek and Coleto Creek, proposed R.O.W, for Coleto Creek Reservoir Flume No. 3. Collected 8/12/83.

Uniomerus sp., (probably *U. tetralasmus*; 4 pairs of valves; 1 left valve and 9 left valve fragments; 4 right valve fragments)

Toxolasma texasensis (1 right valve, female)

CONTEMPORARY FRESHWATER MUSSELS IN THE GUADALUPE RIVER

At least 12 species of mussels have been recorded by the Academy of Natural Sciences of Philadelphia from the Guadalupe River near Victoria (Academy of Natural Sciences of Philadelphia 1991:Tables IV-1 through IV-6) from 1949 to 1973. In addition, there are a number of *Megalonaias nervosa* specimens from the Carlisle Creek locality (see discussion below under that species). Table 9.1 shows the species list near Victoria.

Table 9.1. Contemporary (1949-73) Freshwater Mussels From the Guadalupe River Near Victoria.

Amblema plicata
Anodonta grandis (=*Pyganodon grandis*)
Anodonta imbecillis (=*Utterbackia imbecillis*)
Cyrtonaias tampicoensis
Lampsilis teres
Lampsilis hydiana
Quadrula apiculata
Quadrula aurea
Quadrula petrina
Quincuncina mitchelli
Toxolasma texasensis
Tritogonia verrucosa

Source: Academy of Natural Sciences of Philadelphia (1991:Tables IV-1 through IV-6).

FRESHWATER MUSSELS FROM HOLOCENE ARCHEOLOGICAL DEPOSITS

Freshwater mussel assemblages have been identified from two other archeological sites in the Coleto Creek drainage, the Smith Creek Bridge site (41 DW 270) about 54.6 km upstream in De Witt County, and 41 GD 21 and 41 GD 21A, located about 7.5 km away on the Sulphur Creek arm of the reservoir. Mussels from 41 GD 21/21A were identified by Harold Murray (nine species), and those from the Smith Creek Bridge site (seven species) by Robert Howells. Both assemblages are probably mostly late Holocene. The Threeridge (*Amblema plicata*) is the most abundant species at both sites (Table 9.2).

Table 9.2. Freshwater Mussel Species from Nearby Holocene Archeological Deposits.

Smith Creek Bridge site (41 DW 270; source, Howells 2002:Table 67)
Amblema plicata
Cyrtonaias tampicoensis
Lampsilis hydiana
Lampsilis teres
Lampsilinae, unidentifiable
Megalonaias nervosa
Quadrula apiculata
Quadrula sp., unidentified
Toxolasma texasensis
41 GD 21A and 41 GD 21 (source, Fox 1979:Table 10)
Amblema plicata
Carunculina parva (= *Toxolasma texasensis*)
Cyrtonaias tampicoensis
Lampsilis anodontoides
Leptodea fragilis
Quadrula petrina
Quadrula pustolosa
Quadrula quadrula
Quadrula sp., unidentified
Tritogonia verrucosa

FRESHWATER MUSSELS FROM THE UPPER DEPOSITS AT BERGER BLUFF

Two lots of freshwater mussels (six species) from David Brown's excavations in the upper deposits (levels 1 and 2 only) were identified in 1985 by Raymond Neck (n.d.), at my request. Table 9.3 shows the taxonomic composition.

Table 9.3. Freshwater Mussels from the Upper Deposits at Berger Bluff.

Species	Left valves	Right valves	Row total
Levels 1 and 2			
Amblema plicata	1	1	2
Quadrula apiculata	2	2	4
Cyrtonaias tampicoensis	4	0	4
Lampsilis teres	1	0	1
Toxolasma texasensis	1	2	3
Level 1			
Amblema plicata	70	52	122
Quadrula apiculata	1	0	1
Quadrula petrina	27	19	46
Lampsilis teres	3	0	3
Toxolasma texasensis	1	1	2
Unidentified			97
Grand total:			285

Source: Neck (n.d.)

Neck, commenting on these lots of shell, remarks:

> *Quadrula petrina* is usually found in streams with moderate current over a coarse substrate, i.e. sand or gravel…In summary, the freshwater bivalves from the two samples examined are indicative of a stream with a coarse substrate with possibly somewhat greater flow than Coleto Creek during historical times. The uneroded condition of the umbos indicates presence of alkaline water. As reported by

> Murray (1979), all specimens of all species are from small individuals. This diminutive size was most pronounced in *Quadrula petrina*. The shells of Q. petrina may indicate the past existence of a short-lived population in feeder streams. Such populations may have periodically been extirpated as water flows decreased during drought times. Permanent populations may have been present in the lower reaches of Coleto Creek and possibly the mainstem of the San Antonio River (Neck n.d.).

Amblema plicata is also the most abundant surface-collected species found at the nearby site of 41 GD 31 (Brown 1986;7).

SHELL PRESERVATION AND TAPHONOMY

As would be expected, shell preservation is much better in the upper deposits than in the bench deposits. Shells from the bench deposits are fragile, powdery, and subject to delamination, although the larger and more complete specimens can be identified to the species or generic level without difficulty. There are more shell fragments than complete or nearly complete valves, in part because valves were sometimes struck by shovels or trowels during excavation, or simply fragmented as the matrix was broken up. Much of the mussel shell in the collection shows evidence of fresh breakage, making it difficult to determine whether the shell was already broken when encountered, or simply broke during exposure. In some cases, complete or nearly complete valves were exposed *in situ*, but the thinnest part of the valve opposite the umbo was little more than a powdery stain that broke away when the rest of the valve was extracted. As a result, the lab photos of specimens from the bench included in this chapter show valves that are somewhat less complete than when they were first exposed. Active groundwater movement during much of the early history of the site has affected shell preservation, and although phreatic carbonate has helped to buffer the potential acidity of the quartz sand matrix, it also made it very difficult to expose and recover shells without damage.

However, there are several shells that definitely had evidence of old breaks when they were encountered. The best examples are a cluster of smashed *Amblema plicata* valves in unit N109 E96, stratum 2D, associated with a debris scatter in the upper part of the unit. Included are two *Amblema plicata* left valves that had been smashed with a hard percussor, plotted in place at 92.69 m (Fig. 4.50, upper plan, item 2 and shown as Fig. 9.1) and at 92.68 m (Fig. 4.50, upper plan, item 4), both lying concave side down. Slightly deeper are two smashed *Amblema plicata* right valve fragments, both plotted at 92.62 m and found lying concave side up (Fig. 4.50, upper plan, items 1 and 3). This debris scatter is associated with radiocarbon assay AA 2831.

There are at least three additional examples with pre-excavation breakage. One is an *A. plicata* right valve fragment from the stratum 2C/2D contact in N112 E99 (92.89-92.60 m). Another is an *A. plicata* left valve that was apparently incomplete and missing the umbo when exposed, plotted and photographed in place (N111 E101, 92.19 m, stratum 2A, valve 2). In unit N109 E96, at 92.28 m, an unidentified shell fragment was found and plotted in stratum 2B (near Feature 7, but below detection elevation). There are also three *Amblema plicata* valves (two left, one right) removed from stratum 2A whose status is ambiguous. These have extensive fresh breakage as a result of collection, but may have old breakage as well. A single *Megalonaias nervosa* left valve removed from stratum 2A in the cutbank was evidently incomplete when found, and the single example of *Quadrula apiculata* collected somewhat over 20 m downstream from the excavation area, probably from stratum 2A is very incomplete and has at least some old breakage, although most of the incompleteness may be due to chemical dissolution.

Figure 9.1. Closeup of Old Break on *Amblema plicata* Valve. N109 E96 (92.69 m), left valve. No scale.

Along with this evidence of pre-burial breakage (most likely by human occupants of the site), a number of complete valves were found, plotted, and photographed in place and will be illustrated in the section on shell distribution.

A few specimens show evidence of heat alteration. One is calcined (lot B-133, N109 E96, 92.60-92.55 m, unidentified lateral hinge tooth fragment). There are some unidentified heat-discolored lateral tooth fragments (lot B-82, N111 E101, 92.25-92.20

m), possibly from an *Amblema* left valve plotted *in situ* in the level, and another discolored and heated lateral tooth fragment, unidentified but morphologically consistent with *Amblema* (lot B-48, N110 E102, 92.35-92.30 m). In lot B-76 is another lateral hinge tooth fragment (N111 E101, 92.55-92.50 m) that is only slightly discolored and has probably experienced less intense heating. It is unidentified, but is from a left valve comparable to a modern *A. plicata*. Finally, in lot B-134 is a small flake of unidentifiable shell with mostly old breakage. It has a dark, iridescent color and may have been slightly heated.

The presence of several valves, probably all from adult *Amblema*, with evidence of heat discoloration and fragmentation of the hinge area suggests the interesting possibility that heat may have been applied locally to the hinge area to relax the adductor muscle (cf. Neck 1987:232). It is probably no coincidence that nearly all of the few heat-discolored fragments discovered come from this same area of the valve.

Because the mussel shells from the bench are so fragmented, it is difficult to compile an accurate specimen count. For example, a single excavation level might yield a very large number of freshly broken, powdery, delaminated slivers of shell. Do they represent a single shell broken during excavation, or two, or more? If there are many wall fragments but no umbo present, then an MNI count of “one” must be recorded (and that is the procedure that has been used here for the stratigraphic inventory), but it must also be recognized that more than one valve might have been present. It is also clear that counting only umbos would result in a substantial undercount of the sample size. Table 9.4 represents the best possible estimate of the number of specimens recovered from the bench.

Table 9.4. Stratigraphic Distribution of Freshwater Mussels in the Bench.

Stratum	Definite *A. plicata*	Probable *A. plicata*	*M. nervosa*	*Q. apiculata*	Unidentified	Row totals
3						
3/2D		1			1	2
2D	4				2	6
2D/2C	1				1	2
2C						
2C/2B		2				2
2B		1			2	3
2B/2A						
2A	10	1	1	1	2	15
2A/1						
1	1					1
Column totals:	16	5	1	1	8	31

SPECIES ACCOUNTS

Amblema plicata (Threeridge), 16 definite and 5 probable specimens (Fig. 9.2)

A total (NISP) of 21 specimens can be assigned to this species. A "specimen" is either a single valve or a shell fragment that is sufficiently isolated in space that it is reasonably certain that it is not simply a fragment derived from a valve in an adjacent level or unit. Normally, information on size and side would be used to compile an MNI count since there are two valves per individual, but the bench specimens are too fragmentary to allow this. In fact, there is no evidence that any of the valves are paired, and it is likely that the MNI count is not much smaller than 21. In addition, it is very likely that the five unidentified specimens represent additional *A. plicata* valves.

"Probable" specimens are fragments that are morphologically compatible with *Amblema plicata* but are too incomplete for definite identification. In some cases these can be sided but not identified. Based on size, all specimens are adults except two which are probably on the borderline between juvenile and reproductively mature (see Stein 1969).

The present range for *Amblema plicata* (also termed *Amblema costata* or *Crenodonta peruviana* in some of the older literature) covers most of Texas except the Llano Estacado, Rolling Plains, and the Rio Grande and Pecos River drainages (see map in Howells, Neck and Murray 1996:35). At archeological sites within this area, it is perhaps the most consistently recovered species of freshwater mussel of any, and when it is present, it is very often the most abundant taxon. In other words, it ranks very high both on "ubiquity" and "abundance" indices, probably because it is cosmopolitan in geographic distribution and habitat preference, can tolerate drought, and is large enough to serve as a good food resource. There are a few major archeological projects in south Texas where other species ranked higher. For example, at Choke Canyon Reservoir, *Amblema* was a very minor taxon and the collections from most of the major sites were dominated by *Cyrtonaias tampicoensis* and, to a lesser extent, *Lampsilis* species (Murray 1982), but at most sites reported in the literature, *Amblema* seems to dominate the collections. Beyond Texas, the species extends throughout the Mississippi River basin into Canada. It also is often the most abundant species documented in contemporary freshwater mussels surveys of water bodies such as the Navasota River (Littleton 1979:20), the Little Brazos River (Little and Gentner 1970:Table 1), the Blanco River (Horne and McIntosh 1979:Table 10), and reservoirs in Tarrant County (Mauldin 1972:15), as well as rivers outside Texas (Cummins 1994:Fig. 5).

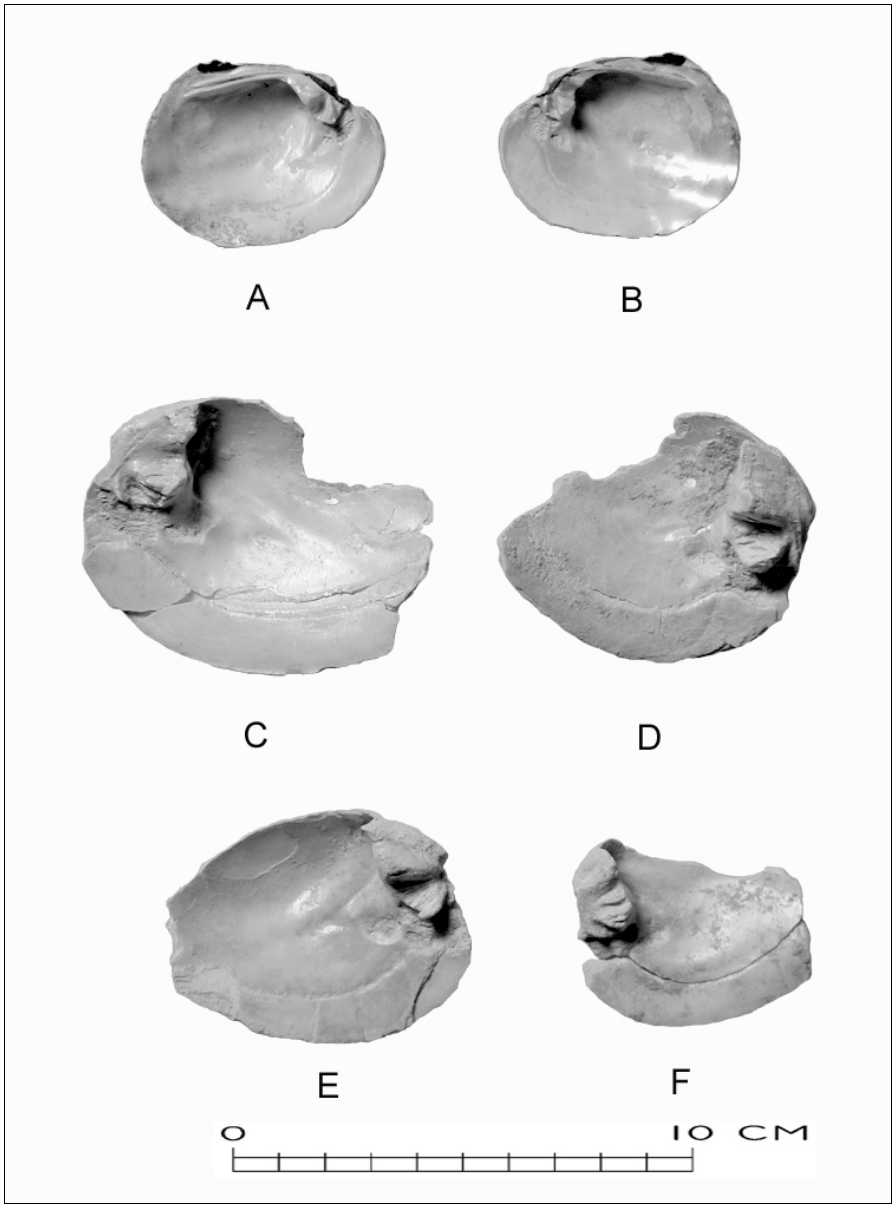


Figure 9.2. Contemporary and Archeological *Amblema plicata* Valves. A and B are disarticulated but paired valves from a recently dead individual found on Smith Creek, De Witt County; C-F are archeological specimens from the bench deposits at Berger Bluff. A, Diatom locality D-19, paired left valve, recently dead with partial loss of periostracum; B, matching right valve; C, Lot B-132-1, N109 E96, 92.62 m, right valve with old break; D, cutbank north of N111 E101, specimen 1 from stratum 2A, left valve; E, cutbank north of N111 E101, specimen 2 from stratum 2A, another left valve; F, cutbank north of N111 E101, specimen 3 from stratum 2A, right valve.

It should also be noted that *Amblema plicata* and *Megalonaias nervosa* are closely related (Mulvey *et al*. 1997:Fig. 1), and *A. plicata* specimens closely resemble smaller versions of *Megalonaias*. Juvenile *Megalonaias* individuals could easily be mistaken for *A. plicata* (however, Raymond Neck has examined the mussels from the bench deposits and checked my identifications). Morphological differences between the two species are discussed by Howells, Neck and Murray (1996:82).

Habitat Preference: Cosmopolitan, occurs on most substrates except deep shifting sand, at water depths of 2.5 cm to 1.5 m, current velocities 0-45.7 cm/second in creeks, rivers, and lakes. This species is a habitat generalist. It can tolerate stranding (Waller, Rach and Cope 1995), droughts and low water quality, but Horne and McIntosh (1979:125) found it to have less tolerance for low dissolved oxygen levels than other mussel species in the Blanco River. On the other hand Chen (1998) found that *Amblema plicata* was better able to maintain oxygen consumption under poorly oxygenated conditions than other species which are normally found in faster-flowing, better oxygenated water. Texas populations are abundant in firm mud and mud-gravel bottom types (Howells, Neck and Murray 1996:34). Horne and McIntosh (1979:Table 1) found them most abundant in the Blanco River in cobble, gravel and pebble bottoms, less so in sand, and still less so in silt and mud, but they have been found in soft, thick mud in Minnesota (Imlay 1972) and Oklahoma (Branson 1982:40). The shell is rather heavy and thick, and the characteristic ridging adds strength. According to Starrett (1971:298), it is one of the more pollution-tolerant species found in the Illinois River. It was found at average depths of about 77 cm and 99 cm (weighted by number of specimens) in Lake Gonzales and Lake Wood (Arsuffi, Whiteside and Perry 1995:Table 1, 2). According to Murray and Leonard (1962:48) it is found in 2-8 feet of water in Kansas. According to Parmalee (1967:26), it

is usually found in 1-3 feet of water in Illinois, usually in sand and gravel, but tolerating mud. In the Meramec River basin of Missouri,

> *A. p. plicata* was found in every substrate encountered except shifting sand, and was most often found in a silt or gravel and cobble substrate. This species was found in 1 inch to 5 feet of water in standing (0.0 ft./sec. at bottom) to swiftly-moving (1.9 ft./sec. at bottom) water (Buchanan 1980:30).

According to Parmalee and Bogan (1998:63), it has been collected in 30 feet of water. Miller and Payne (2004) found very high densities of *A. plicata* in a gravelly shoal in the Big Sunflower River of Mississippi, a river that elsewhere is slow-moving and turbid with a silty sand substrate. Density of all species was 235 individuals per square meter, of which 90% were *A. plicata* (Miller and Payne 2004:148, 150). Hart (1995) surveyed mussels in the Otter Tail River in Minnesota and collected 2432 *A. plicata*. He reports

> Threeridges showed a marked preference for fast (80 cm/s), deep waters (175 cm) and were rarely found in slow, shallow areas…. Threeridges were found in all substrate types, with the most suitable areas dominated by gravel substrates (Hart 1995:29).

Population Density: Howells (1996) reports average densities of 7.2 individuals per square meter in the Guadalupe River between Gonzales and Lake Wood. Horne and McIntosh (1979:Table 1) report densities of more than five individuals per square meter in cobble, gravel, and pebble substrates, and less than one per square meter in silt-mud substrates. Maximum range of density was zero to 6.8 individuals per square meter (Horne and McIntosh 1979:Table 10). Little and Gentner (1970) report recovering 110 individuals from a pool 5-7 m wide and about 40 m long in the Little Brazos River, Robertson County. That translates to roughly 0.46 individuals per square meter in a mud

and loose sand substrate. Golightly (1982:Table 5) reports densities of 12.54, 11.31, and 1.51 individuals per square meter from two different sampling localities on the Little Brazos River. Virginia Mauldin makes the following observation from artificial reservoirs in Tarrant County:

> In water approximately 0.75 meters deep, in an area no more than 2 meters square, at the base of a small clump of reeds in Lake Worth, at least 300 living specimens of A. plicata were collected. This density was not observed at any other time or place, even though at the time this site was discovered, a rather thorough search was made in the vicinity. I have not found references to similar distributional patterns in the literature (Mauldin 1972:15).

Vanleeuwen and Arruda (2001) studied several creeks, tributaries of the Neosho River in Kansas, and found low densities: 0.002 individuals/m^2 on Canville Creek, 0.013 002 individuals/m^2 on Flatrock Creek, and 0.021 002 individuals/m^2 on Labette Creek (Vanleeuwen and Arruda 2001:Table 3). Hart (1995:Table 3) found densities ranging from zero to 23.48 per square meter in the Otter Tail River. Peltier (2002:Table 2) found densities ranging from less than 10 to as much as 150-200 individuals per square meter in the Sunflower River in Mississippi, at depths of one to 2-3 meters, with current velocities ranging from 10 cm/second to 25-35 cm/second. Timed collections of *A. plicata* with snorkel gear in Oklahoma have recovered anywhere from zero to 168 individuals per hour (Vaughn 2003:Table 1). In the Midwest, *Amblema plicata* has been classified into a distinctly deepwater form, *A. plicata peruviana*, and a shallow-water form, *A. plicata costata* (Murray and Leonard 1962:47-50, Plate 7) and Warren (1991:Table 1) follows this classification in his quantitative analysis of habitat scores, but the distinction is not recognized in Texas.

Size and Age of Contemporary Individuals: Maximum shell length reported for Texas is 14.8 cm but has been reported up to 18 cm in Missouri (Howells, Neck and Murray

1996:34). Other maximum reported sizes are “seldom exceeds 170 mm” (Parmalee and Bogan 1998:62); “to 17.2 cm” (Couch 1997:27); “adults commonly 1 to 7 inches long” (17.8 cm, Buchanan 1980:30); “to 7 inches (17.8 cm)” (Cummings and Mayer 1992:40); and 15.6 cm in Canada (Clarke 1973:35-36). Maximum length in Arkansas has been reported at 13.80 ± 4.21 cm for the White River but only 8.70 ± 0.78 cm for the Ouachita River (Christian *et al*. 2000:Table 2). Shells reaching the largest of these maximum sizes represent exceptionally old individuals. An individual 14.8 cm long might conceivably be well over 30 years old. The largest size for immature individuals is 4.40 cm according to Haag and Staton (2003Table 1), or 3.40 cm for males (three years old), according to Stein (1969). Females 5.20 cm long (four years old) were reproductively mature.

Table 9.5 shows length statistics for *Amblema plicata* from various parts of the central United States. Length, width (“height”) and thickness (“depth” or “inflation” in some of the literature) can all be measured, but most of the biological literature reports only length. For fragmented archeological specimens, single-valve thickness is often the only measurement that can be made accurately, but it is difficult to find any comparable measurements in the biological literature. The upper part of Table 9.5 lists a few individual specimens from the Berger Bluff catchment and the Guadalupe River. Most are too damaged for meaningful comparison. The lower part of the table lists length means, standard deviations, median, range, and sample size for various contemporary populations. Some of these collections are from lakes, and others from rivers. Although riverine species are said to be larger and heavier than those of natural lakes (Parmalee and Bogan 1998:21), within a single species living in both habitats, freshwater mussels from stable lakes perhaps live longer, grow to a larger size, and have lower mortality rates than those from rivers, even rivers that are not flood-prone. Some collections have

also been affected by commercial musseling activity, which tends to reduce average length.

Table 9.5: Length Statistics for Contemporary *Amblema plicata*, Central United States.

	Length cm	Mean cm	SD cm	Median cm	Range cm	N	Notes
Individual specimens							
D-19, Smith Creek	5.42						
D-20, Coleto Creek (Preiss Ranch)	>5.70						1
D-20, Coleto Creek (Preiss Ranch)	>5.23						1
Guadalupe River at Carlisle Creek	>6.48						2
Guadalupe River at Carlisle Creek	6.56						
Guadalupe River at Espiritu Santo	6.36						
Guadalupe River at Espiritu Santo	3.24						
Statistics for collections							
Lake Gonzales, Texas		10.34	1.9	10.75	5.00-13.00	86	3
Lake Wood, Texas		9.44	2.04	10	4.50-13.00	35	3
Both data sets combined		10.08	1.98	10.5	4.50-13.00	121	4
Guadalupe R., L. Wood to Gonzales		8.42	1.14	8.89	5.08-10.16	57	5
Navasota River, Texas		8.7			3.70-11.20		6
Little Brazos River, Texas					3.90-10.60		7
Neosho River, Kansas		12.06				16	8
Neosho River, Kansas		11.15				17	8
Mississippi River (Naimo *et al*.)		7.01			2.20-11.20	200	9
Mississippi River (Hornbach *et al*.)					4.00-11.50	498	10
Illinois River, Illinois		6.21			2.78-9.94	2650	11
Silver Lake, Illinois		7.45			2.00-11.50		12
Chippewa River, Wisconsin		10.54	0.33		1.80-15.30	37	13
Red River, North Dakota-Minnesota		11			7.40-14.50	42	14
Little Tallahatchie R., Miss., females		7.56	0.38		3.22-9.96	22	15
Little Tallahatchie R., Miss., males		7.75	0.53		3.78-11.35	19	15
Sipsey River, Alabama, females		8.54	0.45		5.25-11.56	17	15
Sipsey River, Alabama, males		8.8	0.59		3.60-11.13	13	15

Notes

1. Possible subfossil shells, very fragmentary (minimum length only)
2. Fragmentary (minimum length only)
3. Arsuffi, Whiteside and Perry (1995)
4. Statistics for Lake Wood and Lake Gonzales data sets combined
5. Howells (1996)
6. Littleton (1979:20)
7. Little and Gentner (1970:Table 2)
8. Obermeyer (1997:Table 3)
9. Naimo *et al.* (1992:Table 1) mean of means
10. Hornbach *et al*. (1996:Fig. 2)
11. Starrett (1971: Table A-13)
12. Tucker (1996:Table 1)
13. Balding (1992:Table 1)
14. Cvancara (1970:72)
15. Haag and Staton (2003:Table 1)

The largest mean lengths in the table are from Lake Gonzales, the Neosho River, the Chippewa River and Red River of North Dakota and Minnesota, but the most useful data sets in this table are the geographically close samples from Lake Gonzales, Lake Wood, and the Guadalupe River between Lake Wood and the city of Gonzales (Arsuffi, Whiteside and Perry 1995; Howells 1996). For Lake Wood and Lake Gonzales, the mean length for the combined data sets is about 10 cm, with some old, large individuals ranging up to 13 cm in length (Fig. 9.3). The mean length for Guadalupe River specimens is 8.15 cm (with the largest examples over 10 cm long). All three of these populations have experienced commercial mussel harvesting at some point in the past. The Guadalupe River specimens are probably more representative of the size to be expected in Coleto Creek than are the collections from lakes, even though the Guadalupe River is a much larger stream than Coleto Creek.

There are limited data on average weight of the species. Chen (1998:22) reports a mean individual weight of 192.44 ± 8.23 g (n = 15), evidently including the shell. Peltier (2002:Table 3) reports average dry tissue weights of 11.32 ± 5.9 g, 14.62 ± 7.1 g, and 12.69 ± 4.5 g for *Amblema* from three different sampling stations on the Sunflower River. Howard (1999:104-105) measured an average dry tissue weight of 22.6 mg per milliliter of internal shell volume and an average caloric content of 4.48×10^3 cal/g.

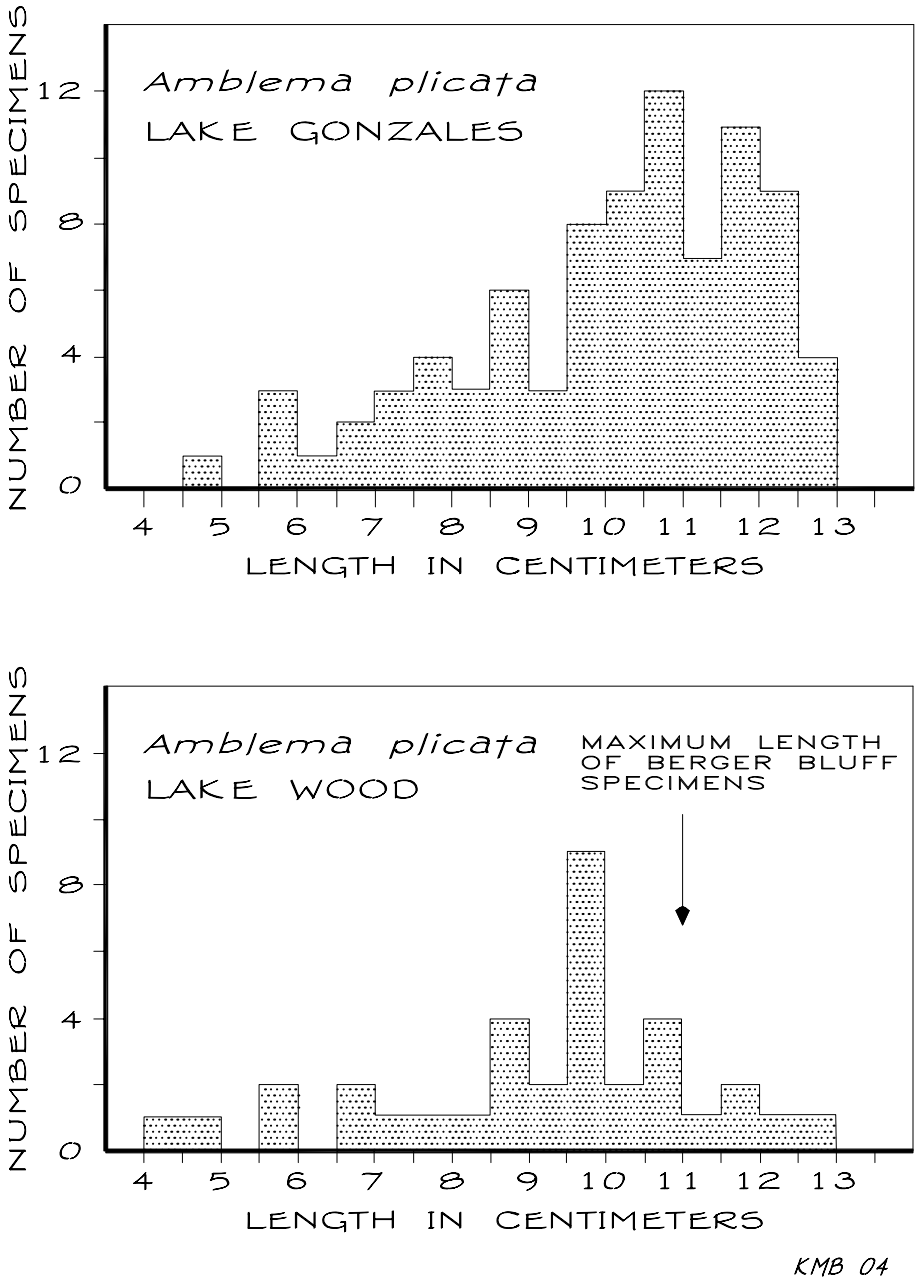


Figure 9.3. Histograms of Shell Length for Contemporary *Amblema plicata*. These specimens were collected in 1995 by researchers from Southwest Texas State University (Arsuffi, Whiteside and Perry 1995:Table 1, 2). Top, Lake Gonzales; bottom, Lake Wood. Arrow shows estimated maximum size of specimens from Berger Bluff bench.

ESTIMATED SIZE AND AGE OF *AMBLEMA PLICATA* FROM THE BENCH

Table 9.6 shows estimated lengths for *Amblema plicata* specimens from the bench deposits. Three were extracted from the cutbank, and the rest derive from the excavations. There are several intersecting levels of uncertainty built into this table. Some specimens are definitely *A. plicata*, while others are probably *A. plicata*, but cannot be definitely identified. Some lengths are based on field measurements (to the nearest half centimeter) taken while the valve was still *in situ* and their accuracy depends on how careful the fieldworker was. Some lengths are based on measurements of cleaned and curated specimens in the lab, and their accuracy depends on how much edge loss occurred during excavation and cleaning. Still others (and these include the largest specimens) were obtained for badly fragmented specimens by comparing the remaining part to a graded series of modern comparative specimens of known length. This last technique has limited precision, but I feel it is about as accurate as the other two techniques. In most cases, it was possible to obtain a fairly good match with a modern specimen by carefully observing edge curvature and relative size of pseudocardinal teeth. Field measurements of length are invariably greater than measurements repeated in the lab, indicating some loss of specimen edge during excavation and removal.

Table 9.6 shows that all except two or three specimens are adults, and most are rather large adults. About 11 specimens are above the median length for modern Guadalupe River examples and at least six are about 11 cm long, which is larger than the largest Guadalupe River specimens (but not those from Lake Wood or Lake Gonzales). Clearly, these are large adults – not record length, but larger than the mean size for many of the contemporary populations listed in Table 9.5.

Table 9.6. Allometric Estimates for *Amblema plicata* Specimens from the Bench Deposits.

Lot number	Length (cm)	Method of measurement	Estimated age (years)
B-33	11	Estimated by comparison	18.5
B-67	<4.5	Estimated by comparison	5
B-76	11	Estimated by comparison	18.5
B-82-1	>4.91	Lab measurement	>6
B-83-2	8.5	Field measurement	11.5-28
B-83-3	10	Field measurement	15
B-83-4	8.5	Field measurement	11.5-28
B-83-5	7	Field measurement	8.5-12
B-89	4.5	Estimated by comparison	5-5.5
B-91	7.78	Estimated by comparison	10-17
B-98-1	7.74	Estimated by comparison	10-17
B-98-2	11	Estimated by comparison	18.5
B-98-4	7?	Estimated by comparison	8.5-12?
B-108-1	11	Estimated by comparison	18.5
B-130-1	10.5	Estimated by comparison	17
B-130-2	7.75	Estimated by comparison	10-17
B-132-1	11	Estimated by comparison	18.5
B-132-2	11	Estimated by comparison	18.5
Cutbank 1	10.75	Estimated by comparison	17.5
Cutbank 2	10	Estimated by comparison	15
Cutbank 3	9	Estimated by comparison	12.5

Notes: Lots with the form B-XXX-X are individually plotted specimens. This list includes both 16 definite and 5 “probable” *Amblema plicata*. Lot numbers B-82-1 and B-98-4 were badly damaged in excavation.

Allometric relationships for freshwater mussels are usually estimated with von Bertalanffy growth curves of the form

$$L_t = L_\infty - (L_\infty - L_0) * \exp(-kt)$$

where

L_t = length at specified time
L_∞ = maximum adult length
L_0 = length at birth
k = a growth constant

These growth curves can be created for contemporary populations when both the length and age (usually from counting growth rings, but sometimes from mark-and-recapture studies) of each individual in a large sample are known. In Figure 9.4, I have created von Bertalanffy growth curves for *Amblema plicata* length using the parameters L_∞, L_0, and k estimated by Christian and others (2000:Table 2) for *Amblema plicata* from the White River and Ouachita River in Arkansas. As the figure shows, the growth trajectories are different in the two river basins, with White River *Amblema* having faster adult growth. Nevertheless, if the curves can be approximated to Coleto Creek, at least a rough estimate of the ages of the bench specimens can be read from this graph. The White River curve suggests that 11 cm long specimens should be about 19 years old (the Ouachita River curve does not apply because it does not rise much over 8 cm). Specimens 7 cm long should be 9-12 years old, depending on which curve is used. This technique can be used to find estimated ages for all the specimens with known lengths (Table 9.6).

Obviously, this procedure incorporates a lot of uncertainty, both in estimating the length of the archeological specimens and in using modern growth parameters from Arkansas. The parameters from Arkansas themselves have large uncertainties attached

(for example, L_∞ for the White River is 137.96 ± 42.10 mm). Another possibility would be to use the data from the Guadalupe River, or Lake Wood and Lake Gonzales, and fit a von Bertalanffy curve to those data, but I am not sure the results would be any more applicable to Coleto Creek than the White/Ouachita River data. At best, the Arkansas data applied to the archeological shells from Berger Bluff allow a rough ballpark estimate of individual age. Figure 9.5 shows another set of allometric data from the Illinois River, a large river with commercial musseling activity. The growth curve is almost identical to that for the White River.

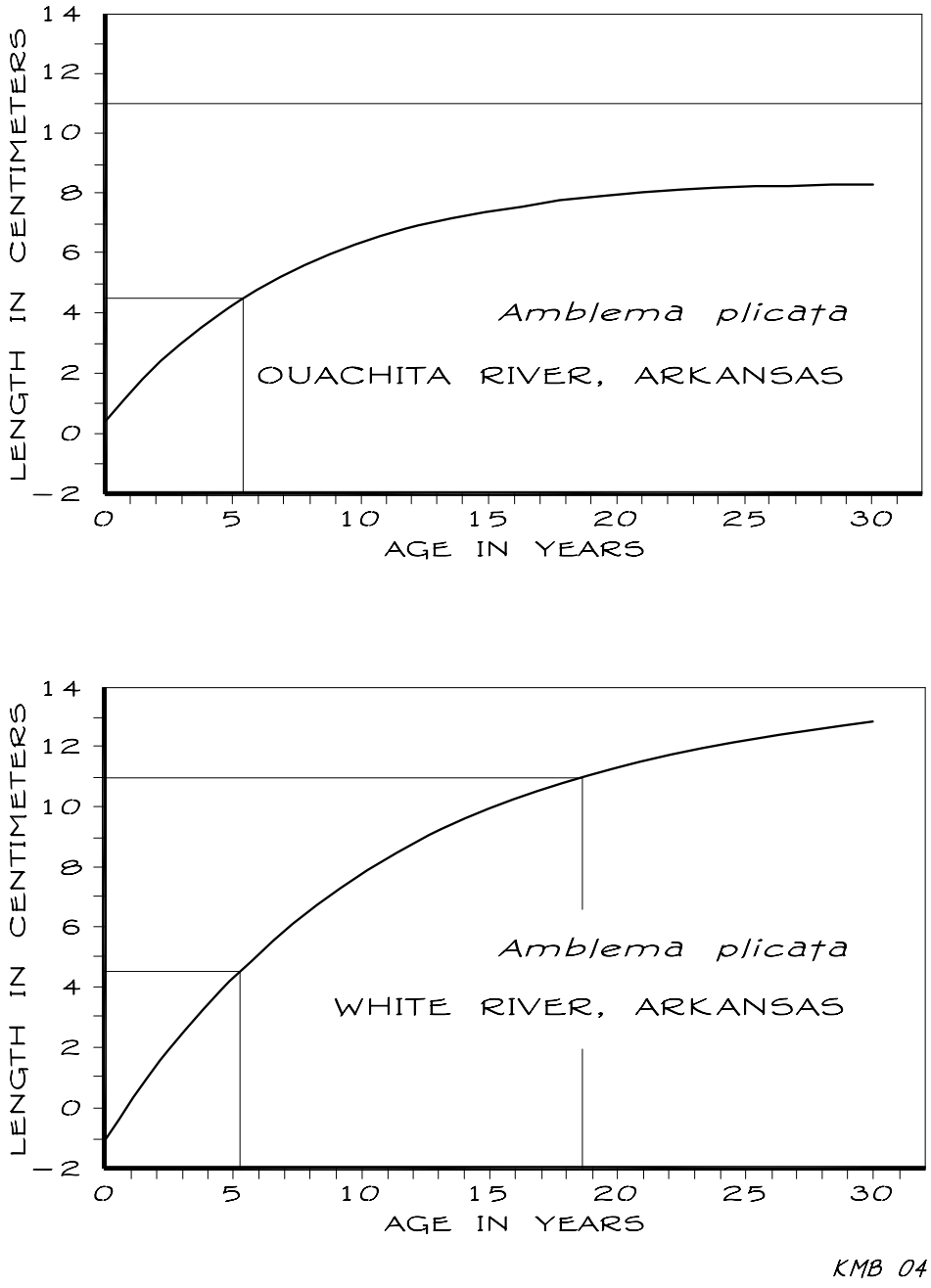


Figure 9.4. Von Bertalanffy Growth Curves for Contemporary *Amblema plicata* From Arkansas. Straight lines intersecting curves indicate estimated minimum and maximum lengths of specimens from the bench deposits. Note slower growth rate for Ouachita River population. Curves are plotted from parameters estimated by Christian and others (2000:Table 2).

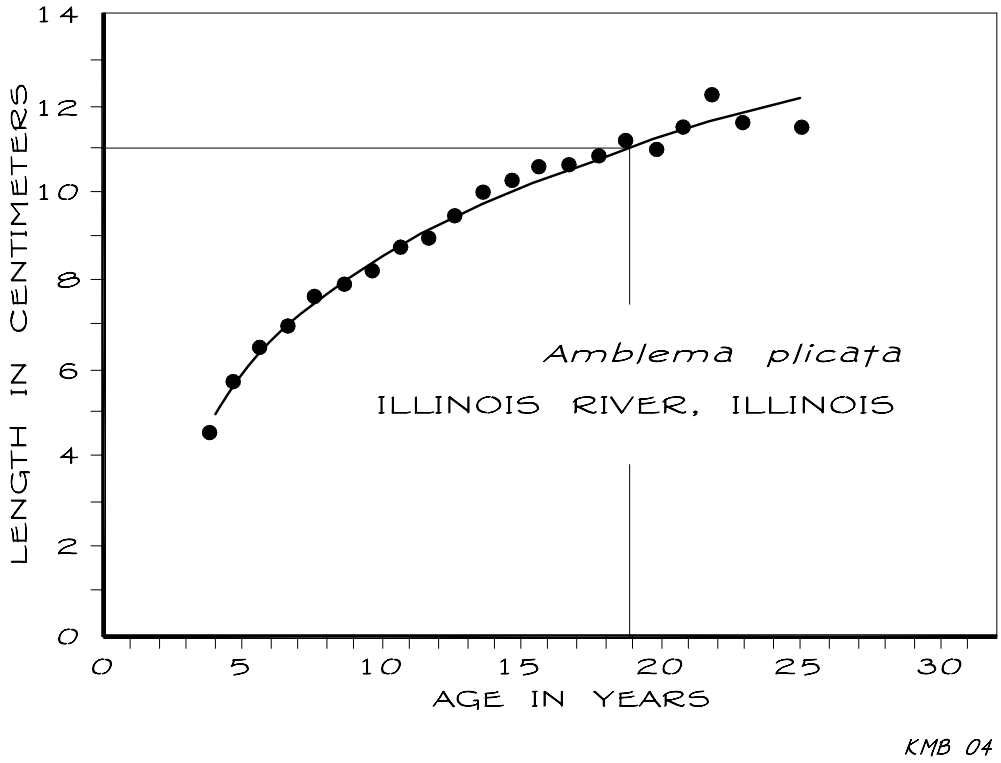


Figure 9.5. Approximate Growth Curve for Contemporary *Amblema plicata* From the Illinois River. Samples collected in 1966 (Starrett 1971:Table A-13). Curve is not a von Bertalanffy curve, but a logarithmic curve of the form

$$\text{length} = 3.8924 * L_n\,(\text{years}) - 0.4294$$

Megalonaias nervosa (Washboard), 1 specimen (Fig. 9.6, 9.7)

Also termed *Megalonaias gigantea* in the older literature, the Washboard (or Giant Washboard) is the largest North American freshwater mussel. This specimen is a fragment of a moderately large adult left valve. It was collected from stratum 2A in the cutbank in the excavation area and evidently was fragmentary when found. The part that survives is the umbo portion, the thickest-walled part of the shell. It is extraordinarily thick, about 2.40 cm in wall thickness, which seems to be considerably thicker than

modern valves estimated to be of comparable length collected from the Guadalupe River. The much thinner posterior part of the shell is missing. From examination of what survives, this appears to be a very massive, robust valve, even more so than contemporary specimens. It seems to compare best to a recent specimen 17 cm long collected from the Guadalupe River.

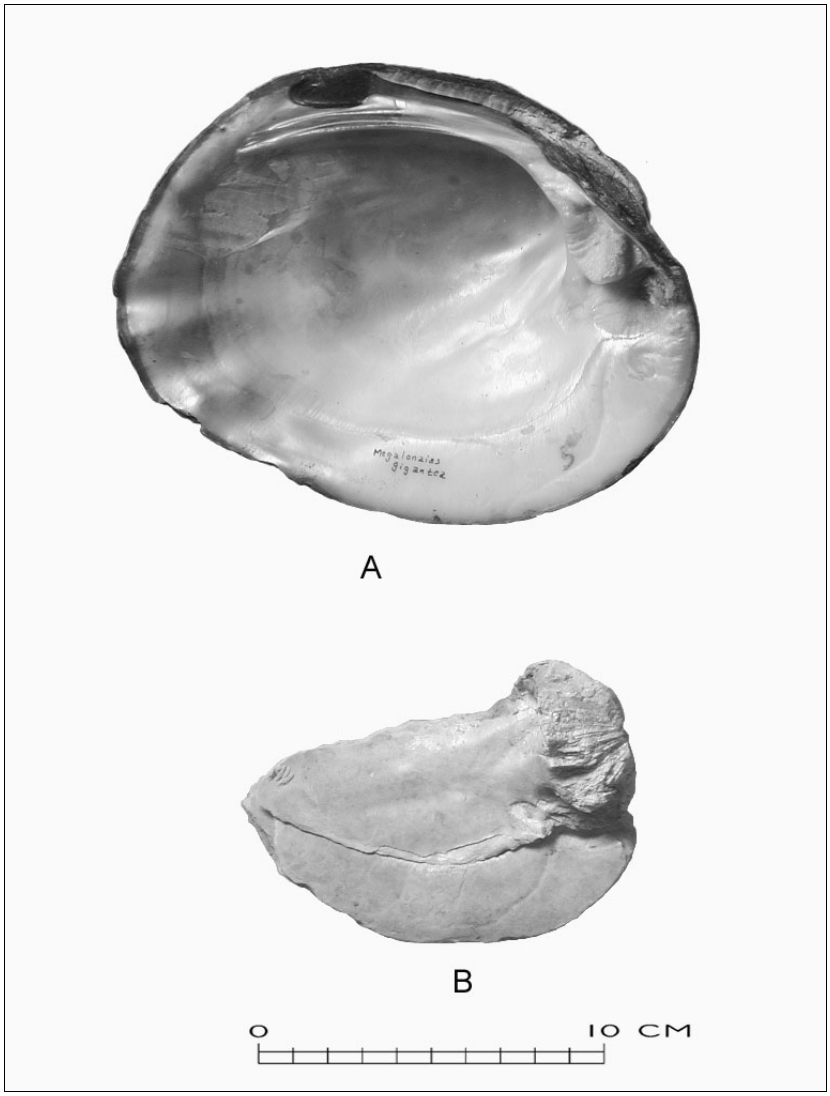


Figure 9.6. Contemporary and Archeological *Megalonaias nervosa.* A, comparative specimen (left valve) from Guadalupe River. B, fragment of left valve from stratum 2A in cutbank, Berger Bluff bench.

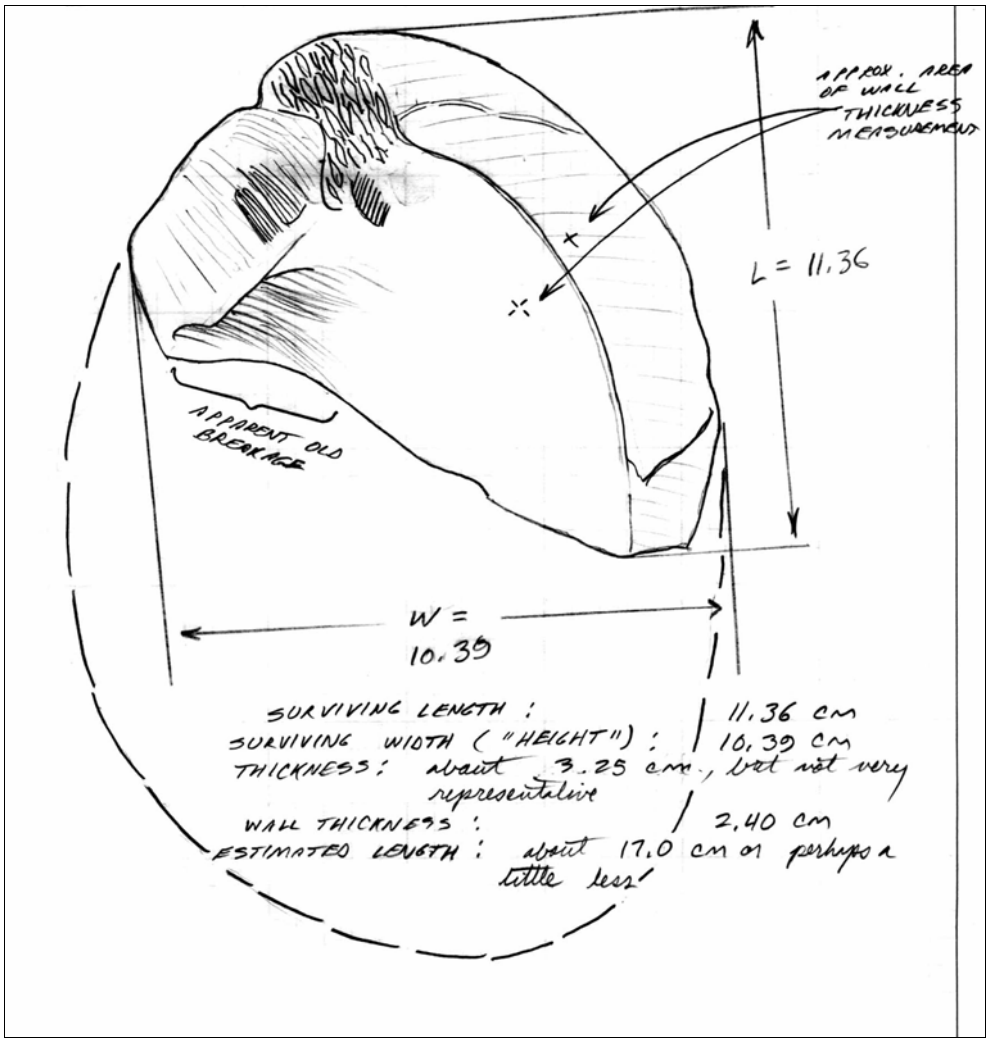


Figure 9.7. Lab Sketch of *Megalonaias nervosa* Valve.

This specimen seems out of place in the Coleto Creek drainage, because Washboards are most often found in deep water in large rivers (although there are exceptions -- see habitat data below). Perhaps because of this, they are less common in archeological middens than many other species. Two of these (out of 701) were found at the Smith Creek Bridge site (Howells 2002:Table 68). Because the Smith Creek Bridge

site is much closer to the headwaters of the drainage system, it is very difficult to envision Smith Creek supplying any pools large or deep enough to support Washboards. At present, Smith Creek is only a few centimeters deep, and it cannot have been much deeper prehistorically. A more likely scenario is that both specimens were imported overland from the Guadalupe River by the site's inhabitants. The same argument applies to Berger Bluff, although here the site is much farther down the drainage and the potential for deep pools is greater. The channel was deeper here in the Late Pleistocene, and perhaps even until the Late Prehistoric (see discussion in Chapter 4), but was it deep enough to sustain a population of *Megalonaias nervosa*, or was this specimen also packed in from the Guadalupe River, either overland or upstream? The species has also been reported from the Payton Branch site (Huebner 1997:20), located at the confluence of Payton Branch and Perdido Creek on the south side of Coleto Creek Reservoir.

Post (1982) performed proximate analyses of *M. nervosa* tissue to evaluate it as a meat source. His data indicate an average meat weight of 119.88 ± 34.89 g (range, 71.71-185.44 g; Post 1982:Table F-1). The meat contained an average of 84.41% moisture, 6.29% protein, and 0.65% crude fat, but when converted to dried flour, contained 40.71% protein and 3.70% crude fat (Post 1982:128). He also analyzed fatty acids that could possibly be used to recognize a signature for meat residues in archeological deposits (dominant fatty acids were C16:0 and C16:1).

Because this is usually a deep-water species, it may sometimes be difficult to collect live by wading or diving, but shells are sometimes exposed on sandbars by flooding in larger rivers -- and because the shell is so massive, it was probably often collected as raw material for artifacts by prehistoric foragers. Small numbers of

Megalonaias shells in archeological sites distant from deep-water habitats may indicate collection and long-distance transport as raw material, rather than food remains, and that scenario may be relevant to the specimen from the bench deposits (see Theler 1991:325; Shaw *et al*. 1998:1591). Long-distance transport of shellfish as foodstuff (rather than artifact raw material) up to 12 km has been documented in Australia by McNiven (1992). At Choke Canyon Reservoir, *Megalonaias nervosa* was recovered from 14 sites investigated in Phase 1. Most sites produced only one or two specimens, but four were recovered from 41 MC 72, and 13 from 41 MC 15 (Murray 1982:554). Small numbers of the species have also been recovered from the Wilson-Leonard site (Shaw *et al*. 1998:Table 37-14), from five sites investigated at O. H. Ivie Reservoir (Treece *et al*. 1993:Table 9.10), from Bear Creek Shelter (Lynott 1978:Table 16), from the McKenzie site (Neck 1987:Tables III.2, III.4, III.6), from 41 DT 59 (Fullington 1995; Todd 2000:Table 1), and from the Scott site in Oklahoma (White 1977:Table 1). A very unusual and remarkable record of *Megalonaias* use comes from Early Archaic context at two sites on the Concho River (215 valves, or MNI = 111 at 41 TG 307; 228 valves, or MNI = 121 at 41 TG 307; Lintz 1996:Table 6). One of the *Megalonaias* specimens from O. H. Ivie Reservoir comes from Cultural Unit 6 (thought to be Late Paleoindian in age by the investigators) at the Turkey Bend Ranch site (Treece et al. 1993:231-232). The contemporary distribution of the species is similar to that of *Amblema plicata*, except restricted in Texas mostly to river reaches east of the Balcones Escarpment (see map, Howells, Neck and Murray 1996:83). The early Holocene archeological specimens from the Concho River/upper Colorado River area are far beyond the present range of the species. This is undoubtedly a significant indicator of major hydrological changes since the early Holocene. Metcalf (1982:46-47, 51, Table 1) reports finding this species in Late

Pleistocene sites (including one with an assay of 13,620 ± 300 RCYBP on shell) in Eddy County, New Mexico. The range also extends into Nuevo León.

Habitat Preference: Howells, Neck and Murray describe the habitat preference of *M. nervosa* as follows:

> Washboards typically occur in large, low-velocity, deep rivers on mud or gravel…. Neck [1982b] indicated washboards require 6.1-22.4 m depths and Murray and Leonard (1962) did not collect the species at depths less than 1.8 m. However, several individuals were taken in Lake Wood and Lake Gonzales, Gonzales County, Texas, at 0.9-1.2 m, and the species was found abundant in the Little Brazos River at 0.3-0.9 m in depth, though such occurrences are atypical. Though typically a large-river species, washboards can adapt to conditions in some reservoirs. Buchanan (1980) reported the species from silt, gravel, cobble, or mixed cobble and boulders in standing to moderately fast (45.7 cm/second) waters. Williams and Schuster… found washboards in the Ohio River at depths greater than 18 m (Howells, Neck and Murray 1996:81).

Murray and Leonard (1962:44) list the habitat as "quiet places in muddy bottoms in large streams having deep water." In the Meramec River basin, Buchanan (1980:25) reports

> *M. nervosa* most commonly occurred in a silt, gravel and cobble or cobble and boulder substrate or some combination of the three. This species was found in 1 inch to 5 feet of water in standing (0.0 ft./sec. at the bottom) to moderately-flowing (1.5 ft./sec. at the bottom) water.

Post (1982:Table F-1) recovered specimens from the Tennessee River in 15-25 feet (4.6-7.6 m) of depth. Washboards can evidently be fairly abundant in favorable habitats, but may be found in fewer places than other species. For example, Littleton found them at only six of 37 stations on the Navasota River, in mud and gravel bottoms at depths of a few centimeters to one meter (Littleton 1979:38, Table 2). In contrast, *A. plicata* was found at 11 stations. A survey of Neosho River tributaries in Kansas yielded

the species at only one out of 40 stations, compared to five for *A. plicata* (Vanleeuwen and Arruda 2001:Table 2).

Population Density: Howells (1996) reports average densities of 2.0 individuals per square meter in the Guadalupe River between Gonzales and Lake Wood. Golightly (1982:Table 5) reports densities of 0.20 and 0.75 individuals per square meter from two different sampling efforts at one locality on the Little Brazos River. Vanleeuwen and Arruda (2001:Table 2) report a density of 0.002 individuals per square meter on Cherry Creek in Kansas. Starrett (1971:Table 8) reports that significant numbers could be retrieved in very short periods of fishing from boats with crowfoot dredges in the Illinois River in 1966. Other reports from the upper Mississippi River suggest densities up to 7.6 per square meter. Dawley (1947) found them only in large rivers in Minnesota.

Size and Age of Contemporary Individuals: Specimens in Texas commonly reach lengths of 20-23 cm (Howells, Neck and Murray 1996:81). Parmalee and Bogan (1998:160) report 25 cm for Tennessee, and the largest confirmed length is apparently about 28 cm (Cummings and Mayer 1992:24; Howells, Neck and Murray 1996:81). Very large individuals like these would be very old, since Starrett (1971:Table A-11) reports an age of 26 years for individuals 16.7 cm long. Woody and Holland-Bartels (1993:60) report the following percentages of reproductively mature adults at various ages: 4 years (0%), 5 years (17%), 6 years (27%), 7 years (56%), and 8 years (93%).

Howells (1995) measured 18 specimens from the Guadalupe River between Gonzales and Lake Wood, and found an average length of 13.26 ± 1.32 cm (range, about 11.4-15.2 cm). Table 9.7 shows measurements for individual specimens (mostly unprovenienced) in the TARL comparative collection, from two lots collected at the

confluence of Carlisle Creek and the Guadalupe River, near Cuero, De Witt County, and for three specimens from Lake Gonzales. The few measured larger collections that I could find listed are also shown. Most Texas specimens seem to average less than 15 cm in length, usually ranging between about 11 and 18 cm for adults.

Woody and Holland-Bartels (1993) studied *M. nervosa* in the upper Mississippi River and found individuals ranging in age from three to 34 years and ranging in length from 3.1 to 16.1 cm. They defined the relationship

$$\text{length} = 6 + 30 * \log_n (\text{age})$$

This function (Fig. 9.8, top) yields an age of almost 40 years for an individual 17 cm long, perhaps implying slower growth for these more northerly populations. A logarithmic function fitted to Starrett's Illinois River data (Fig. 9.8, bottom) yields an age estimate of about 22 years for an individual 17 cm long. A von Bertalanffy curve (not shown) fitted to parameters estimated from Ouachita River data (Christian *et al*. 2000:Table 2) yields an estimate of about 23 years for an individual 17 cm long.

If the length estimate (17 cm) for the very incomplete Berger Bluff bench specimen (based on comparison with a modern valve) is reasonably accurate then it probably represents an individual 22-23 years old or younger (but probably no younger than 14) at death. Like the *Amblema plicata* specimens, this individual was probably larger than the mean size for contemporary populations, but smaller than the contemporary maximum length. If the growth rate for more northern populations (like those shown in the top part of Figure 9.8) is more appropriate for a Younger Dryas-aged specimen, then this individual may be even older.

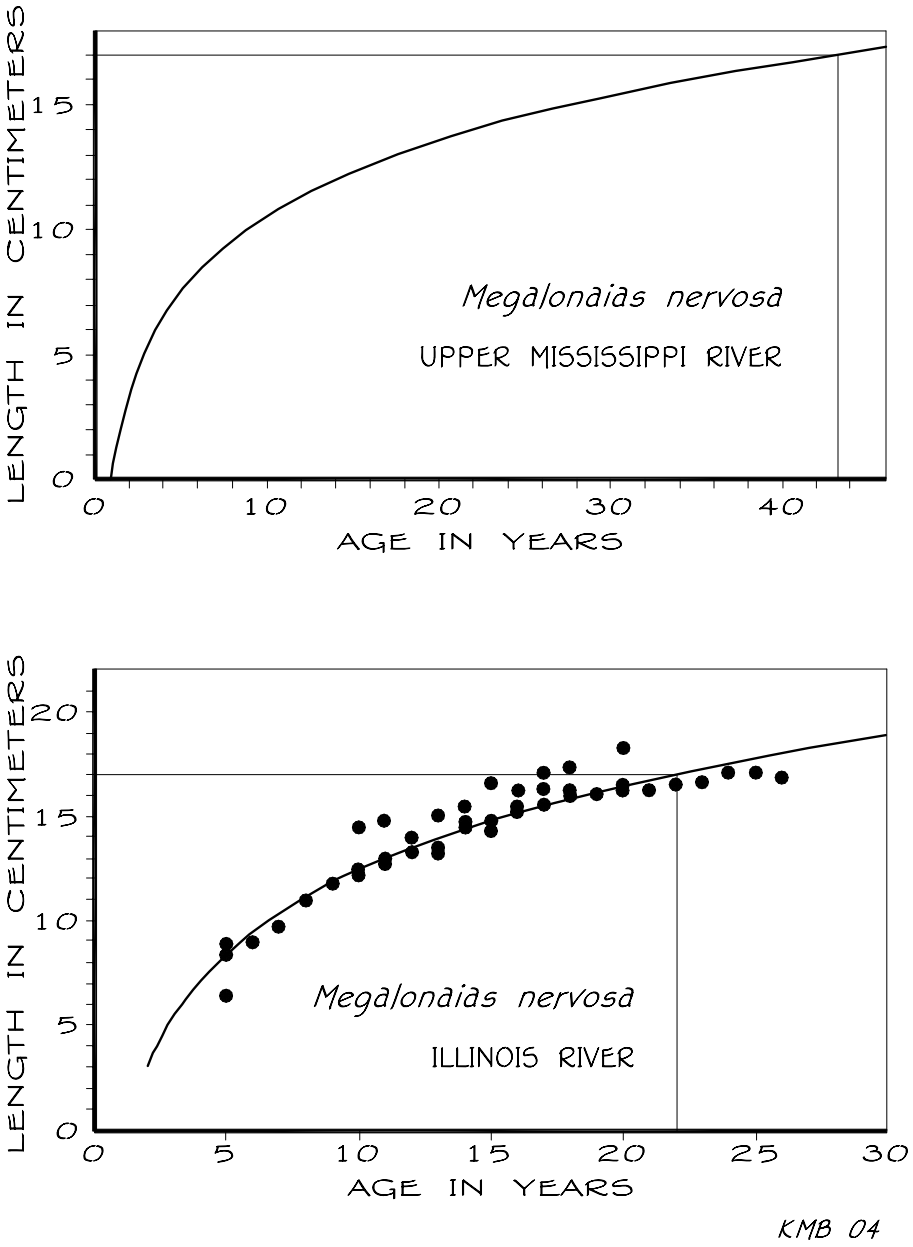


Figure 9.8. Growth Curves for *Megalonaias nervosa*. Top, logarithmic curve defined by Woody and Holland-Bartels (1993:60) from the upper Mississippi River (Minneapolis to Cairo); bottom, logarithmic curve fitted to Illinois River data provided by Starrett (1971:Table A-11). Intersecting lines are estimated age and size of the bench specimen. The curve takes the form

$$\text{Length} = 5.8289 * L_n(\text{age}) - 1.0067$$

Table 9.7. Length Statistics for Contemporary *Megalonaias nervosa*.

	Length cm	Mean cm	SD cm	Median cm	Range cm	N	Notes
Individual specimens: TARL Collection							
1. left, pair	17.2						1
1. right, pair	17.0						1
2. left, pair	19.3						2
2. right, pair	19.4						2
3. left	20.5						3
Guadalupe River at Carlisle Creek, De Witt County, 1996							
4. left, pair	9.96						4
4. right, pair	9.91						4
5. left	14.4						4
6. left	13.8						4
7. left	14.1						4
8. left	13.4						4
9. left	12.9						4
Guadalupe river at Carlisle Creek, De Witt County, no date							
10. articulated pair	10.88						5
11. right	12.55+						5
12. right	11.01						5
13. right	11.37						5
14. (broken)	--						5
15. right	15.3						5
16. left	11.29						5
17. left	9.75						5
Lake Gonzales, Texas	19.0						6
Lake Gonzales, Texas	20.0						6
Lake Gonzales, Texas	17.0						6
Statistics for collections							
Guadalupe R., Lake Wood to Gonzales		13.26	1.32		11.43-15.24	18	7
Navasota River, Texas		15.20			11.60-19.50		8
Illinois River, Illinois		14.29	2.80	15.24	2.80-18.29	55	9
Tennessee River		14.56	1.73	14.55	11.85-17.60	192?	10

Notes
1. TARL comparative collection, Guadalupe River, paired valves
2. TARL comparative collection, Guadalupe River paired valves circa 23.5 years old?
3. TARL comparative collection, Guadalupe River single valve circa 20 years old?
4, 5. Collections by Bob and Patsy Goebel, confluence of Carlisle Creek and Guadalupe River
6. Arsuffi, Whiteside and Perry (1995:Table 1)
7. Computed from unpublished data furnished by Robert Howells (cf. Howells 1996)
8. Littleton (1979:38)
9. Computed from Starrett (1971:Table A-11)
10. Mean of the means, computed from Post (1982:Table F-1)

Quadrula apiculata (Southern Mapleleaf), 1 specimen (Fig. 9.9)

Until recently, the Southern Mapleleaf has not been recognized as a separate species. In the older literature, it was considered a subspecies of *Quadrula quadrula*, so there are not many published descriptions relating specifically to this taxon. The exterior surface of the shell is distinctive, as it is covered with small bumps ("pustules"). The Berger Bluff specimen was found in the cutbank, possibly at the same level as stratum 2A, somewhat over 20 m downstream from the excavation area. The location is well away from the bench area, but inside the limits of the site as mapped on the blufftop. This specimen was identified by Raymond Neck as a *Q. apiculata* right valve.

Quadrula apiculata has been found in small numbers at various archeological sites such as Rice's Crossing (Howells 2003), 41 TR 174 (Lintz 2004:Table D-1), 41 DL 270 (Anthony 1994), the McKenzie site (Neck 1987), 41 ML 195 (Gardner 2002), 41 MM 340 and 41 MM 341 (Howells 2001), the Hurricane Hill site (Zimmerman 1999), and various sites at Stacy Reservoir (Seay 1989) and Fort Hood (Gardner 2003). They were recovered in moderate numbers at various sites at O. H. Ivie Reservoir, mostly in Late Archaic and Late Prehistoric context (Treece and others 1993:Table 9.10). Two specimens were recovered from the Smith Creek Bridge (Howells 2002:Table 68) and as noted earlier, one specimen was seen in the lots examined from the upper deposits at Berger Bluff.

At present, the species is widely distributed across most of the eastern two-thirds of Texas (see map in Howells, Neck and Murray 1996:107), extending into northern Mexico and parts of the southeastern United States.

Habitat Preference: *Quadrula apiculata* is sometimes an associate in beds of Threeridges and Washboards. It occurs in either flowing or still water, in various substrates – mud, mud/gravel, mud/sand, and mud/gravel/cobble – down to depths of 4.6 m, but often much less (Howells, Neck and Murray 1996:106). Parmalee and Bogan (1998:210) report it is a large-river and lake dweller. Densities up to 30 individuals per square meter were found at Cedar Creek Reservoir (Howells, Neck and Murray 1996:106).

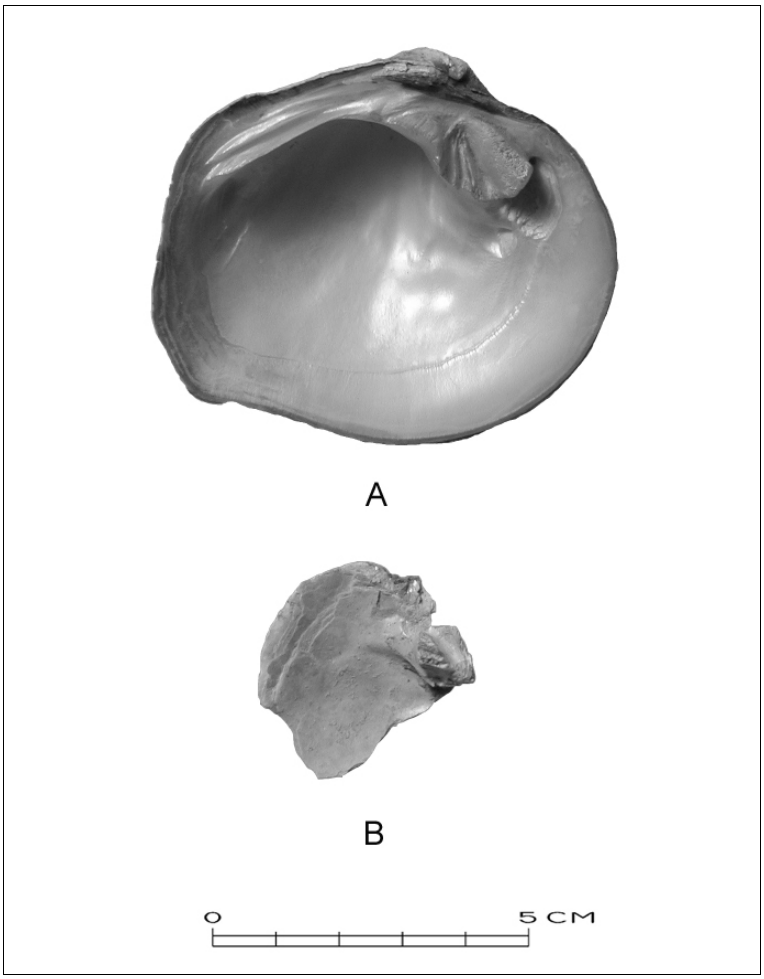


Figure 9.9. Southern Mapleleaf (*Quadrula apiculata*). A, contemporary example from Falcon Reservoir; B, archeological specimen from cutbank at Berger Bluff.

According to Neck (1982a:173), both *Quadrula apiculata* and *Amblema plicata* can survive well in poorly oxygenated water.

Sphaeriid Clams and Peaclams (24 specimens; Fig. 9.10)

Sphaeriid clams (or fingernail clams) and peaclams are diminutive bivalves only a few millimeters in diameter. Although they look like juvenile freshwater mussels, both are members of the family Sphaeriidae (or Pisidiidae in some sources) rather than the family Unionidae. Because the adults are smaller than quarter-inch mesh, they are usually recovered only when fine-mesh screening of alluvial sediments is done, and because they are often associated with small aquatic and terrestrial snails in fine-screened matrix samples, they are often more likely to be treated in the "snail chapters" rather than the "mussel chapters" of archeological reports. None of the specimens from the bench sediments have been identified beyond the family level, although I offer some possible generic identifications in Table 9.8. Under conventional taxonomy, peaclams have been represented by the genus *Pisidium* (five species in Texas) and tend to be even smaller than sphaeriid clams, while fingernail clams are represented in Texas by two genera, *Musculium* (three species) and *Sphaerium* (one species, *Sphaerium striatinum*). However, Lee (2001) has recently revised the taxonomy and presumably the peaclams would now be considered *Cyclocalyx*. Most of the specimens from the bench are well preserved and could probably be identified to species level by a specialist, but correct identification requires specialized knowledge. Specimens from the bench were recovered by three methods: 1) occasional examples fortuitously found on the 1/4-inch screen, 2) specimens picked from N109 E96 bulk matrix screened on fine mesh, 3) specimens recovered from the N110 E102 snail matrix column and identified by Raymond Neck.

Table 9.8. Sphaeriid Clams and Peaclams from the Bench Deposits.

Lot no.	Unit	Level	Shell length (mm)	Side	Stratum	Comment
B-24	N109 E103	92.20-92.15		right	2A/2B	
B-29	N109 E103	92.05-92.00		left	1/2A	*Cyclocalyx?*
B-58	N110 E102	92.05-92.00	10.03	left?	2A	*S. striatinum*?
B-133	N109 E96	92.60-92.55	2.1	right	2D	*Cyclocalyx?*
--	N110 E102	91.85-91.80			1	2 valves*
--	N109 E96	93.08-93.00	2.4	left	2D	*Cyclocalyx?*
--	N109 E96	93.08-93.00	4.4	left	2D	*S. striatinum*?
--	N109 E96	93.08-93.00	2.1	right	2D	*Cyclocalyx* sp.**
--	N109 E96	93.08-93.00	2.8	right	2D	*Cyclocalyx?*
--	N109 E96	93.08-93.00	3.1	right	2D	*Cyclocalyx?*
--	N109 E96	92.75-92.70	5.4	left	2D	*Sphaerium*??
--	N109 E96	92.75-92.70	2.2	fragment	2D	*Cyclocalyx?*?
--	N109 E96	92.55-92.50	2.0	?	2C/2D	*Cyclocalyx?*
--	N109 E96	92.50-92.45	2.9	right	2C	*Cyclocalyx?*
--	N109 E96	92.35-92.30	3.4	left	2B	*Cyclocalyx?*
--	N109 E96	92.35-92.30	3.0	left	2B	*Cyclocalyx?*
--	N109 E96	92.35-92.30	2.7+	right	2B	*Cyclocalyx?*
--	N109 E96	92.35-92.30	2.7	left	2B	*Cyclocalyx?*
--	N109 E96	92.35-92.30	2.2+	right?	2B	*Cyclocalyx?*
--	N109 E96	92.35-92.30	1.9	left	2B	*Cyclocalyx?*
--	N109 E96	92.35-92.30	>1.7	left	2B	*Cyclocalyx?*
	N109 E96	92.35-92.30	--	fragment	2B	Unidentified***
--	N109 E96	92.15-92.10	3.0	left	2A	*Cyclocalyx?*

* Recovered from N110 E102 snail matrix column; Identification by Raymond Neck.
** Identification by Robert Howells.
*** Small fragment, resembles *Sphaerium* or *Musculium*.

In Colorado, *Sphaerium striatinum* averages about 10.5 mm in shell length and *Musculium lacustre* is about 5.8 mm long (Wu 1978:Tables 8, 9).

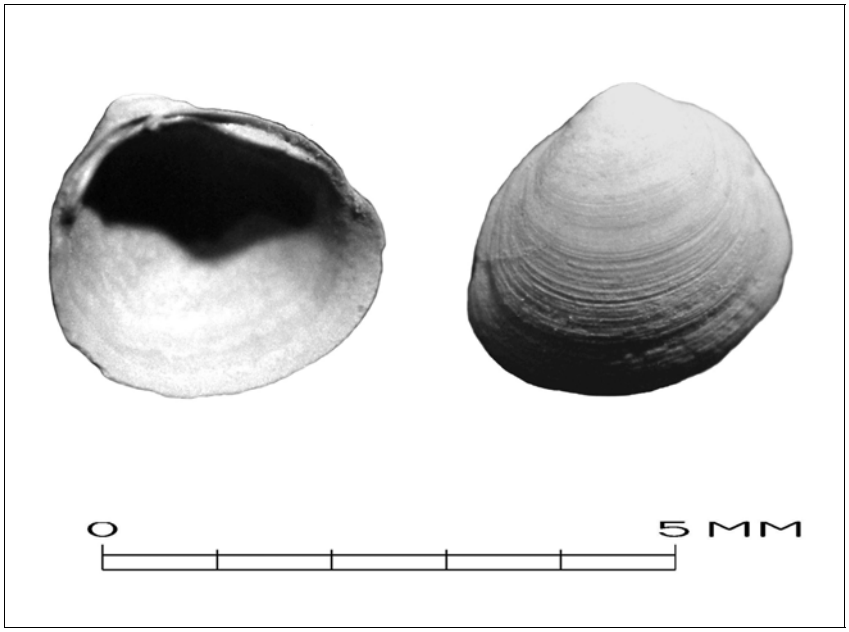


Figure 9.10. Peaclam (?) (*Cyclocalyx?*). Exterior and interior views of the same specimen from N109 E96 (92.15-92.10 m), stratum 2A bulk matrix.

Because fine screening of archeological sediments is becoming more common, fingernail clams and peaclams are now reported in some of the more recent literature. Examples have been found at the Aubrey site (Neck 2001:Table 7.1), Lubbock Lake (Pierce 1987:Table 6.2), Rex Rodgers (Fullington 1978:108-109), 41 DL 270 (Neck 1994:Table 18), Hinojosa site (Murray 1986), Rush site (Quigg and Peck 1995:Table 5.21), Headstream site (Boyd et al. 1993:75), and in Oklahoma, the Burnham site (Theler 2003a, b). Both the Leon Creek and Medina paleosols at the Richard Beene site have produced a single example of *Pisidium* (C*yclocalyx*) *casertanum* (Neck 1992:Table 3).

Habitat Preference: Sphaeriid clams live in ponds, swamps, creeks and larger streams. *Sphaerium striatinum* is cosmopolitan, living in perennial water bodies in various bottom types. Many of the peaclams can be found in deep water [up to 35-40 m for *P. (Cyclocalyx) casertanum*] and on mud or sand bottoms. In Pennsylvania springs, *P.*

casertanum is mostly confined to silty bottoms (Glazier and Gooch 1987:41). *Sphaerium* occurs more often in faster current and coarser bottoms, while *Musculium* is intermediate in preference (Dillon 2000:29), but in general, silty pools are preferred over riffles (Dillon 2000:28-29). The Sphaeriidae have much shorter lifespans than the long-lived unionid mussels. Thomas (1963) studied *Sphaerium (Musculium) partumeium* in a temporary pond and found it had a lifespan of 12-13 months, with the population persisting despite seasonal drying of the pond. She attributes this to environmental hardiness, rapid growth under favorable conditions, and "precocious production of young" (Thomas 1963:42; Way, Hornbach and Burky 1980). *P. (Cyclocalyx) casertanum* normally produces one or two generations per year, but may perhaps live as long as five years in cold, poorly oxygenated, unproductive habitats (Burky 1983:300-301. About 15 embryos on average are produced (Heard 1964). Densities as high as 10,000 per square meter have been recorded for fingernail clams in the upper Mississippi River.

Peaclams and Sphaeriid Clams from the Bench Deposits: All of the Sphaeriidae are so small and lightweight that they can easily be transported by floodwaters, even into the distal parts of floodbasins. A flood event could be expected to disperse specimens widely over the floodplain. Small numbers of specimens (usually one or two valves) were found in most of the levels from N109 E96 for which bulk matrix was picked, suggesting that these diminutive clams were probably widely dispersed as clasts throughout the site, but not concentrated in any one area, unlike the unionid clams. Most of the bench specimens look as though they may be examples of *Cyclocalyx* and have a shell length of 3 mm or less, although that identification is tentative. Peaclams usually average about 2-4 mm in length (Wu 1978:Tables 4-9). One specimen has been definitely identified as *Pisidium* (*Cyclocalyx*) by Robert Howells. There are also a few examples that may be *Sphaerium*

or *Musculium*. Table 9.8 lists known examples. Most come from strata 2B and 2D, but that is chiefly a function of which lots have been examined. Picking of additional lots from N109 E96 would undoubtedly add to this inventory.

THE SHELL-BEARING SURFACE IN STRATUM 2A

All along the cutbank in the bench area, scattered mussel shells are visible in stratum 2A at an elevation of about 92.20 m (shown in Fig. 4.22, but at a scale that is difficult to see). These clearly lie on a single buried surface whose elevation is fairly consistent, although the upper contact of the stratum lies anywhere from 6-16 cm above the surface. Observation of the cutbank profile suggests that the shells are spatially clustered, with large gaps between clusters of shells, but the clusters occur at a consistent elevation over a distance of more than nine meters.

Six excavation units penetrated this shell-bearing surface. Two of these units, N109 E103 and N112 E97, produced no shells, but in the other four, shells were encountered in the profile walls (Figs. 4.30, 4.33, and 4.34) and excavation floors. A cluster of seven shells was found on the north side of unit N111 E101, mostly at 92.17-92.19 m, and another cluster of five shells was found at the corner where units N112 E99 and N113 E98 adjoin (one shell was removed before it could be plotted). Figure 9.11 shows the distribution of these shells in four of the units and Figs. 9.12 and 9.13 show some examples *in situ*.

Unit N109 E96, dug to 92.00 m, was deep enough to have encountered this shell-bearing surface, but instead of shells, uncovered the small colluvial fans discussed in Chapter 4.

Figure 9.11. Plan View of Mussel-Bearing Surface (*following page, landscape view*). The contents of the 92.20-92.15 m level in four excavation units are shown. Items marked by large numbers are plotted valves. Unlabeled small items are bone fragments and a hackberry seed. Plotted valves are as follows:

1, concave up, 92.14 m, *A. plicata* right valve

2, concave up, 92.16 m, unidentified, probably *A. plicata*

3, concave up, 92.13 m, unidentified, probably *A. plicata*

4, concave up, 92.15 m, unidentified, probably *A. plicata*

5, concave up, 92.17 m, *A. plicata* right valve

6, concave up, 92.18 m, unidentified

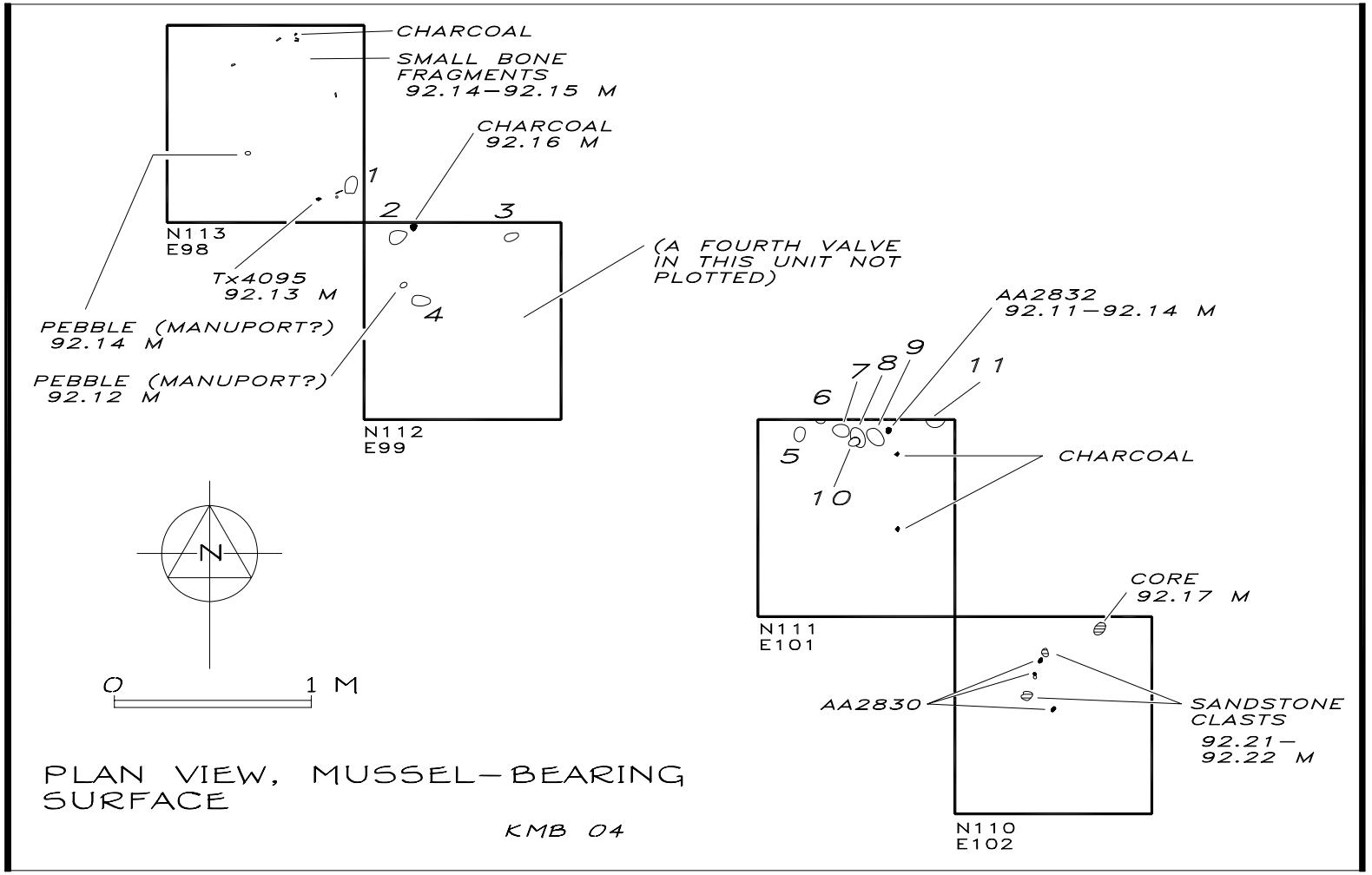
7, concave up, 92.18 m, *A. plicata* right valve

8, convex up, 92.17 m, *A. plicata* right valve

9, concave up, 92.19 m, *A. plicata*, left valve?

10, removed in excavation, ca. 92.21 m, *A. plicata* left valve

11, concave up, 92.17 m, unidentified



PLAN VIEW, MUSSEL-BEARING SURFACE

KMB 04

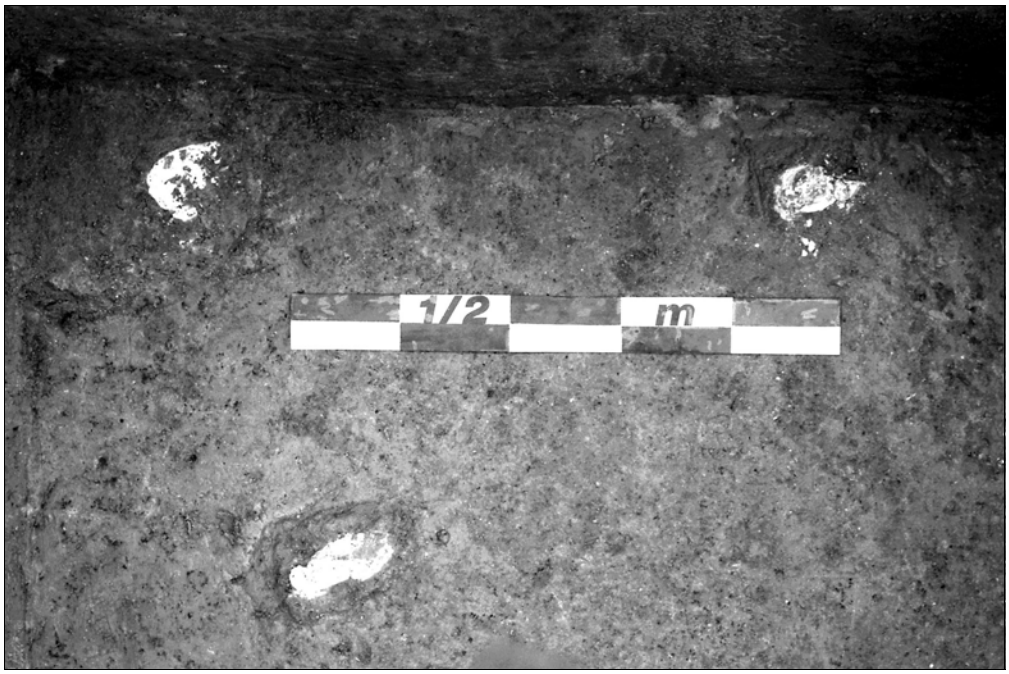


Figure 9.12. Shell-Bearing Surface in N112 E99. Looking down and north at the 92.20-92.15 m level with two *Amblema plicata* valves and one possible *A. plicata* valve exposed. Scale is 50 cm long. These are valves 2, 3, and 4 in the previous figure.

Figure 9.13. *Amblema plicata* Valve in N113 E98. Looking north, 92.14 m, adult (valve 1 in Figure 9.11) in southeast corner resting on shell-bearing surface. Scale is ruled in centimeters.

Because of poor preservation and excavation damage, positive identification of all these shells was not possible, but all of the specimens that could be identified are fairly large examples of adult *Amblema plicata* (Table 9.4). There were no paired or articulated valves. All but one of the valves shown in Figure 9.11 was found with the concave interior (or ventral) surface up. Most of the shells drawn on the cutbank profile are also

concave-up. Since this is the hydrodynamically unstable position for the shell (Fig. 9.13; Brenchley and Newall 1970), it seems unlikely that these shell clusters were formed by flood deposition. The species most susceptible to flood stranding are lightweight species like *Anodonta* (Tucker 1996). Excavation damage also makes it nearly impossible to determine if any perimortem damage to the shells was present. None of the valves seem to show any evidence of heat discoloration, although some heat-discolored lateral tooth fragments were found in the 92.25-92.20 m level of N111 E101. Nevertheless, it is reasonably certain that this thin scatter of Threeridge valves on the former muddy surface of the Coleto Creek floodbasin is the result of predation.

In Chapter 4, I pointed out that heavy clastic material had been thrown onto the floodplain surface later in the history of the bench deposits by a major flood event, but there are no heavy gravel deposits associated with the mussel shells. In addition to the *Amblema* valves, a significant number of small bits and flakes of wood charcoal, some charred bone, a fired clay nodule, two or three chert or quartz pebbles (possible manuports), various small animal bone fragments, some Goliad sandstone clasts, a couple of chert flakes, and a core were found at the same level. The evidence strongly suggests that all of these shells are present as the result of human predation on a nearby *Amblema plicata* shell bed.

Because it is now fashionable in archeology to attribute as many biological remains as possible in archeological sites to natural rather than cultural origins (cf. Erlandson and Moss 2001), it is worth asking whether a non-human predator could have strewn these shells on the stratum 2A surface. Besides humans, the chief mammal predators of freshwater mussels are rodents (muskrats), mustelids (minks, otters)

mephitids (skunks) and procyonids (raccoons). Size-selective predation of muskrats (*Ondatra zibethicus*) on mussels is well-documented for the southeastern United States. They are not members of the Carnivora, but are facultative carnivores. Muskrats forage in mussel beds, taking species roughly in proportion to abundance (Neves and Odom 1989:938), but selectively consuming the larger species and individuals (Diggins and Stewart 2000). In one study from Alberta, the mussels eaten were significantly larger and older than those remaining in the mussel beds (Convey, Hanson and MacKay 1989:Figs. 1, 2; Dillon 2000:Fig. 7.1). In another study from Minnesota, muskrats showed a preference for certain species and certain sizes within a species (medium-sized individuals were preferred, and the smallest and largest individuals were rejected; Tyrell and Hornbach 1998). In the Alberta study, muskrats took mostly mussels less than 7.5 cm long, and in the Minnesota study, most were less than about 8 cm long (modal sizes were about 3-7 cm). The muskrats pry the valves open with their incisors, scratching the periostracum and leaving the unbroken valves attached by the hinge ligament (Neves and Odom 1989:935), or sometimes breaking one of the valves (leaving gnaw marks) and leaving the other intact (Convey, Hanson and MacKay 1989:655). According to Dillon (2000:274), thick-shelled species remain unbroken, while thin-shelled species have one valve broken. Muskrat shell middens (see Parmalee and Klippel 1984:Fig. 2 for a good photo, in which most of the valves appear to be concave up) are created at the feeding stations, located "at burrow openings, undercut banks, stumps, logs and snags" (Neves and Odom 1989:935). The middens are sometimes dispersed by flooding and silted over. They tend to be small in area, but dense. Muskrat middens recorded in Alberta by Convey, Hanson, and MacKay (1989:655) were up to one square meter in size, some containing over a thousand shells, with the local muskrat population consuming 228 ± 24 mussels per day. Neves and Odom (1989:938) recorded one feeding station on the Clinch

River that produced 2080 mussels. Even though muskrats show preferences for certain species, they do a reasonably good job of taxonomic sampling from shell beds: in the study by Neves and Odom (1989), 16 species were found in the muskrat middens, and the study by Tyrell and Hornbach (1998) 11-16 species were found (also see Bovbjerg 1956).

If we consider whether the shell-bearing surface in stratum 2A has the characteristics of a buried muskrat midden, several factors should be considered. The present distribution of muskrats is restricted to the northeastern part of Texas, the Panhandle, and the Pecos and parts of the Rio Grande valleys. Goliad County is well beyond the present range, although it seems quite plausible that muskrats might have been present in the Coleto Creek drainage during the wetter, cooler climate of the Younger Dryas. Raccoons (*Procyon lotor*), river otters (*Lontra canadensis*), American minks (*Mustela vison*), and striped skunks (*Merphitis mephitis*) are known mussel predators whose range includes the study area. Their mussel predation habits are not well documented. While predation on crawdads and snails is much more common for raccoons, otters and minks, they will occasionally eat unionid clams (Schoonover and Marshall 1951:Table 1; Smith, Kennedy and Baumgardner 1987:Table 1; Melquist and Hornocker 1983:Table 10), but food habits studies show these are very minor items. Minks will also eat sphaeriid clams (Casson and Klimstra 1983:Tables 1, 2). Although *Amblema plicata* is not a common species in areas where studies of muskrat predation have been done, muskrats take species that are similar in size (such as various species of Kidneyshell). Small numbers of *A. plicata* are taken in Minnesota (Tyrell and Hornbach 1998:Table 1). On the other hand, the shell scatter in stratum 2A is much more dispersed, the shell count is much lower than is typical for muskrat middens, there is no clear evidence for valve breakage or gnawing, and there are no obviously paired valves.

Furthermore there is clear, if sparse, evidence of cultural debris closely associated on the same buried surface. The single *Megalonaias nervosa* valve recovered probably comes from the same surface. It is too large to have been muskrat prey and was probably broken before burial.

In my opinion, the stratum 2A shell scatter is more likely to be the result of human than muskrat predation. The close association of small amounts of cultural debris is the most convincing argument, and there is also good evidence of human predation (in the form of smashed valves and heat discoloration) on the same mussel species higher in the section (mostly in stratum 2D).

MUD DAUBER NEST (1 SPECIMEN, FIG. 9.14)

During removal of overburden, a segment of a mud dauber nest in stratum 3 was struck with a shovel and split into two halves. The location is shown on Figure 3.1 and is approximately N113.63 E94.92 (93.20 m). The four-chambered nest segment is relatively small (4.2 x 4.7 cm) and was evidently unopened and intact before it was struck by the shovel; however, one side of the segment shows what appear to be four additional chambers in section, filled with and largely obscured by sediment, so evidently the nest had been partially broken open before burial. The original nest evidently contained at least eight larval chambers (if not more), four of which were never exposed and four of which had been broken open. It is a nest of a *Sceliphron* species, most likely *S. caementarium* (Drury), the most common representative of the genus in Texas (Allan Hook, personal communication). There is no evidence the adults had emerged from the nest. This specimen is made of orange-beige silty clay (9YR 6/6) and probably has been baked, based on the somewhat reddened color. Some areas have a dark gray, carbon-

stained appearance. It is coated on the exterior with gray (10YR 7/2) carbonate-cemented sediment and the chambers exposed on the outside (the back side of the section on the left in Figure 9.14) are filled with gray-brown sediment, presumably from stratum 3.

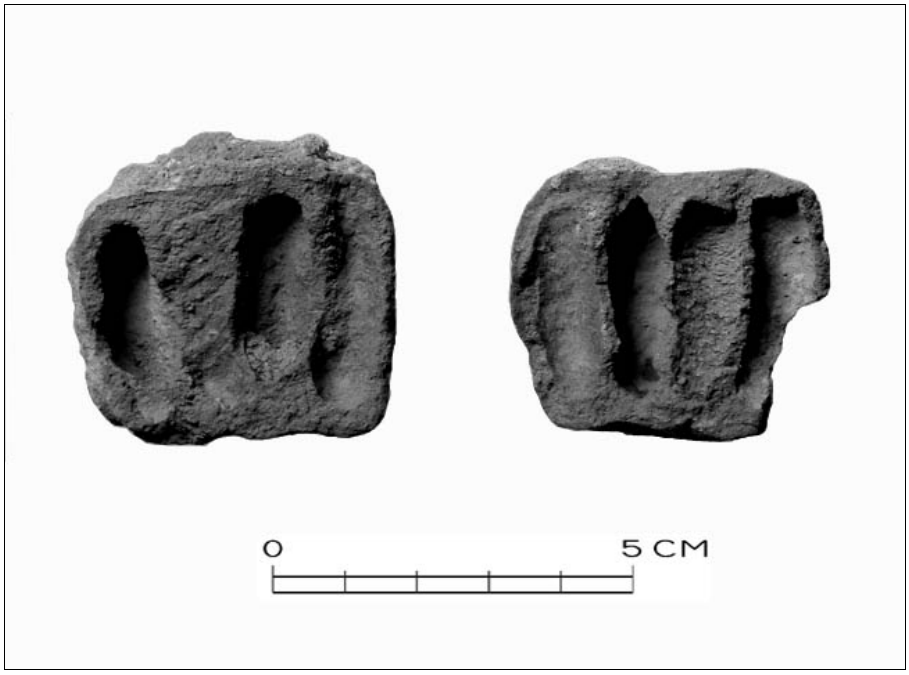


Figure 9.14. Mud-Dauber Nest, Stratum 3.

Mud dauber nests are probably much more common in archeological contexts than is generally appreciated. They are found in historic sites where structures were present, such as Las Cabras in Wilson County (Anne Fox, personal communication) or Fort Griffin (Olds 1969:95) and in prehistoric sites where structures either may or may not have been present, like the Belcher Mound (Webb 1959:27), the Spiro site (Rogers 1982:154), the Weston site (Howard 1970), the Lee site (Richards 1971), the Robinson-Solesbee site (Bell *et al*. 1969:22), the Packard site (Wyckoff 1964:88, Plate XIVA, 1-2), the Bug Hill site (Vehik 1982:112), the Soc site (Figley 1968:56), the Kersey site

(Marshall 1965:136), the Lepold site (Lynott and Monk 1987:19, 21), the Moccasin Bend site (Graham 1964:23, 35), the Cow-Killer site (Reynolds 1984:171), Deadman's Shelter and Deadman's Terrace (Hughes and Willey 1978:185, 219), 41 LK 201 (Highley 1986:84; Hall, Black and Graves 1982:386), the Ham Creek site (Forrester 1964:33, Plate 21, H), Peggy Lake (Gadus and Howard 1990:309, Table 74), Coontail Spin (personal observation of TARL collections, lots 81, 84, 155, 159, 187, 213, and 286), 41 VT 98 (Weinstein 1992:295), and two sites at Cooper Lake (Fields *et al*. 1993: 131, 216-218). They have been recovered from some fairly early sites in Texas, such as Hearth 2 at the Lewisville site (Crook and Harris 1957:58), and the Buckner Ranch site (Nash 2001:Fig. 24). Forty-one nests were recovered from the Wilson-Leonard site, most of them from the Paleoindian levels (Collins 1998).

In cases where baked nests have been discovered at open sites, it has been suggested that either they were inadvertently introduced into fires on firewood (Gadus and Howard 1990:309) or else were intentionally baked and then broken open to extract the cooked larvae (Wilson 1979). The ethnographic record lends some support to the latter idea. The Nisenan of California are known to have roasted yellowjacket larvae (Beals 1933:346). The Paiute cooked and ate yellowjacket and wasp larvae (Heizer 1954:7; Fowler 1989:61), and wasp remains have been found in a human coprolite from the Tehuacan area of Tamaulipas (Marsh 1964:57).

Because nest construction depends on a ready source of mud, nests are most likely to be found where springs, seeps, or muddy creek banks lie close to some sort of protected overhang. Nests can be expected to contain diatoms introduced from the mud source (Sides 1970), although no such analysis has been attempted here. They can also be

dated by optically stimulated luminescence (OSL; Yoshida, Roberts and Olley 2003), although that has not been tried, either.

SUMMARY AND CONCLUSIONS FOR CHAPTER 9

When the freshwater mussel assemblages from the bench deposits, the Late Holocene midden in the upper deposits (and at the Smith Creek Bridge site), and the present-day creek are considered, the differences are striking. The following comments pertain mainly to the unionid mussels.

The bench assemblage has only three unionid species, dominated by large, old adult *Amblema plicata*. All three species (*A. plicata*, *M. nervosa*, and *Q. apiculata*) are often found in fairly deep water, and though they do not prefer sluggish or turbid water, can tolerate muddy bottoms and fairly muddy water conditions. Likewise, the peaclams are often characteristic of deep water and are perhaps more tolerant of turbid conditions than the fingernail clams, which may be why the peaclams seem to greatly outnumber the fingernail clams. This is consistent with the evidence presented in Chapter 4 for deeper water, more equable flow, and higher suspended load characterizing the creek during the Younger Dryas. Threeridges are particularly tolerant of high suspended loads. Howard (1999) carried out laboratory research specifically to find out how well *Amblema plicata* tolerates muddy water. He examined shell growth, tissue condition, filtering capacity, and gaping behavior, and concluded that the species is quite tolerant of high suspended sediment loads (Howard 1999:111).

Many of the mussels in the Berger Bluff bench deposits occur on a buried surface just below the top of one of the muddy depositional units, presumably representing a

period when the creek carried an especially high suspended load. The unionids, especially the *Megalonaias*, are not headwater or temporary pond species – they are characteristic of the middle or lower reaches of streams. Many of the *Amblema plicata* individuals may have been as much as 18-19 years old when they were collected from the creek. This may indicate that the recurrence interval for major floods was greater than 18-19 years, on the assumption that severe flooding might disrupt or remove mussel beds and cause temporary local extirpation. This is consistent with evidence presented in Chapter 4 that severe flooding was absent until late in the history of the bench deposits [note that all of the mussels from the bench underlie (and predate) the major flood event discussed in Chapter 4].

The complete species list for the blufftop midden is unknown, because we only have an inventory for a couple of lots, but there are at least six species, including two (*A. plicata* and *Q. apiculata*) found in the bench deposits. There are many shells in the UTSA-CAR collections that have never been washed or inventoried, and a tally of these would probably add one or two more species to the list. The present list suggests mussels were collected from more than one habitat. *Amblema plicata* and *Quadrula petrina* are the most abundant species. The latter, restricted to the Guadalupe and Colorado River basins, is found in mud, sand or gravel in water less than one meter deep (Howells, Neck and Murray 1996:120). *Cyrtonaias tampicoensis* and *Lampsilis teres* are found in slow to fast water in varying bottom types and can tolerate fairly turbid conditions. *Toxolasma texasensis* is a pond, oxbow lake, or creek species found in mud or sand bottoms. Raymond Neck judged that this assemblage represented “a stream with a coarse substrate with possibly somewhat greater flow than Coleto Creek during historical times.” Although the Smith Creek Bridge site is much closer to the headwater region of the

catchment, the Late Holocene freshwater mussel assemblage there is much the same (seven species), with the addition of *Lampsilis hydiana*, a characteristic East Texas species.

The mussel assemblage in the blufftop midden at Berger Bluff is dominated by small to medium-sized, relatively young individuals that had probably reached reproductive age within the last year or two. Unfortunately, there are no metric data to compare to the bench collection, but the difference is readily apparent when sorting the material, and Raymond Neck confirmed this observation when sorting the two lots he examined. In contrast to the bench deposits, where many of the *Amblema plicata* individuals are up to 11 cm long and might be as much as 18-19 years old, the modal length for the species in the blufftop midden might be about 4-5 cm long, and perhaps no more than five years old. According to Neck, the diminution was even more pronounced for *Q. petrina*. This same preponderance of small shells has been noted at other sites (Anthony 1994:274-275; Irwin, Houk, and Drake 1999:77; Howells 2003:148; Peacock 2000:188-191; Peltier 2002:54). Klippel, Celmer and Purdue (1978:268) have also suggested that *A. plicata* is dwarfed in lakes or streams with slow-moving water.

In summary, there are more species (and a wider range of habitats) in the Late Holocene midden compared to the Younger Dryas-aged mussel population, but the individuals are smaller and younger. What accounts for this difference? I believe there are both cultural and environmental factors at work. I believe that all of these mussels are present in the site as a result of human predation, but the collecting effort in the Younger Dryas/Early Holocene was short in duration and small in scale, yet very selective. In contrast, during the Late Archaic and Late Prehistoric occupations of the site, the

community size was much larger, occupation of the site was much longer, and the site was a base camp rather than a foraging locality. Collecting pressure was much more intense, generating a larger and more diverse sample of mussels, but preventing *Amblema plicata* adults from living much past five years of age. This kind of pressure has been styled "resource depression" (see discussion in Broughton 2002), and most of the zooarcheological research concerning its effects on body size and diet breadth have dealt with vertebrates or marine shellfish (see de Boer, Pereira and Guissamulo 2000; Broughton 2002; Mannino and Thomas 2002:455). There is also the possibility that major flood events were more common during the mesic Late Holocene, perhaps also affecting recruitment of the local mussel populations, and limiting adult size of some of the species. Flood washouts and intense collecting pressure by human populations may have acted in concert to limit age and size. Unionid mussels have much longer lifespans and proportionately much less energetic investment in reproduction than the short-lived, prolifically reproducing sphaeriid clams, and therefore are more susceptible to localized extirpation by flooding. The species richness in the midden is probably also inflated by *time-averaging*. There is a very large quantity of shell in the upper deposits, representing a lot of collecting effort, but it may well be that only three or four species were collected at any one time. Freshwater mussel surveys done in the central and southeastern United States in the last 50 years show that, on average, about two to seven species can be expected at any one collecting station or mussel bed in a particular river or creek – but the variability is very high, and species counts varying anywhere from none to about three dozen are on record.

As for the modern creek, sampling has been unsystematic except for the pre-inundation ecological study. Seven species are known, mostly the same as in the Late

Holocene middens at Berger Bluff and the Smith Creek Bridge site, but with the addition of two thin-walled pond species, *Ligumia subrostrata* and *Utterbackia imbecillis*. Aside from introduced Asiatic clams, *Lampsilis teres*, *Cyrtonaias tampicoensis, and Toxolasma texasensis* appear to be the most common species in the creek today. A pair of *Amblema plicata* valves was found on a sandbar at locality D-19 on Smith Creek. These retain most of the periostracum, indicating that at least a small population of *A. plicata* survives in the Smith Creek drainage. This individual is 5.45 cm long, which is probably comparable to many of the valves in the blufftop midden at Berger Bluff. The appearance of the pond-dwelling *Toxolasma texasensis* in both the Late Holocene middens and the modern channel is interesting. It may indicate the development of deep pools separated by riffles which largely dry up during the dry season.

The increase in species richness from the bench (three species) to the blufftop midden (at least six) is significant, but does it register environmental change or cultural change? When biologists survey aquatic fauna, they use appropriate methods (timed collections, transects, or quadrats) designed to reveal all the species present, in proportion to their natural abundance. Betty Meehan's ethnographic research on Anbarra shellfish foragers in Australia (Meehan 1982, 1983) shows that certain preferred species are heavily targeted for collection. The frequency distribution by species resembles a Poisson curve (Meehan 1982:Fig. 2). On the other hand, she found there was little in the way of size biasing. Exceptionally small shells were discarded, but otherwise no effort was made to collect the largest individuals (Meehan 1983:132-134). When extra species beyond the preferred kind were collected, they were often gotten by children (who had not yet absorbed the adult search image) or older women who were unable to enter deeper water. In other cases, storms had washed up a windfall of mixed species, all of which were then

collected. In still other cases, the targeted species was found to be unavailable, so alternate species were used. Another study of shellfish collecting by Meriam children also shows that children collect a broader range of shellfish, do less field processing, and may be more likely to contribute shells to middens than adults (Bird and Bird 2000:471). All of these characteristics displayed by aboriginal marine bivalve collectors might also apply to the Late Holocene blufftop midden at Berger Bluff.

Freshwater mussels are very scarce in the archeological record for North American Paleoindian sites. It is not clear whether this represents genuine lack of usage or, more likely, poor preservation. There are few sites where mussel shell can easily survive well for 10,000 years, except perhaps dry shelters. Shell clusters were found in deposits dated 7000-9000 RCYBP at the Richard Beene site (Alston Thoms, personal communication). Mussel shell was recovered from the 1959-60 excavations at Levi Rockshelter; some of it was used for a radiocarbon assay. *Lampsilis teres* (formerly *Lampsilis anodontoides*) was the only species identified (Alexander 1963:513). A single example of the same species was also found at the Pavo Real site (Brown 2003:272-273). Some of the most interesting evidence comes from the Lewisville site, where mussel shell, some of it calcined, was found in or near the hearths (Crook and Harris 1957:28, 29, 34, 58). *Amblema plicata*, "Quadrula frustulosa (Lea)" (=*Quadrula pustulosa*?) and "Fusconaia cf. undata (Barnes)" (=*Fusconaia flava*) were identified. Another possible example is the Crockett Gardens site (41 WM 419), about which little is known (McCormick 1982). A single unidentified mussel shell fragment was recovered from the Late Paleoindian Occupation Zone 1 at the Armstrong site in Caldwell County (Schroeder and Oksanen 2002:51). A small sample of mussel shell (six species, mostly *Lampsilis teres*, some *Toxolasma texasensis*, and examples of *Arcidens confragosus*,

Uniomerus tetralasmus, Potamilus purpuratus, and *Quincuncina mitchelli*; Shaw *et al*. 1998:Table 37-14) was recovered from Paleoindian levels at the Wilson-Leonard site. The only examples of *Amblema plicata* and *Megalonaias nervosa* occurred in post-Paleoindian deposits. At Dust Cave in Alabama, only a couple of valves are listed in a preliminary report on the mussel shell (Parmalee 1994:Table 2). Beyond Texas, perhaps the best record of Paleoindian usage of freshwater mussels comes from the Allen site in Nebraska, where there are 25 identifiable valves representing six species. Two examples were calcined and ten others heat-discolored, and one had use wear (Warren n.d.). The mussel shell here was relatively well preserved, perhaps due to the calcareous nature of the loessic sediments (Robert E. Warren, personal communication).

Regardless of whether the scarcity of freshwater mussels in Paleoindian sites is a matter of economics or taphonomy, it is clear that even when mussels are found, at most sites the samples sizes are small, species richness is low (no more than six species), specimen condition is often poor, and it is difficult to determine whether cultural modification of the shell is present. The Turkey Bend Ranch site (41 CC 112) at O. H. Ivie Reservoir stands out as something of an exception. Here 146 shells representing at least eight species (including all of the Berger Bluff bench species) were recovered in Late Paleoindian context (Treece *et al.* 1993:Table 5.76). In contrast to many of the sites already mentioned, which seem to emphasize thin-walled pond-dwelling species, this assemblage includes some deep-water, large-stream species like *Megalonaias nervosa*, and over 27% of the shell showed evidence of burning.

The density of mussel shell in alluvial sites varies on a spectrum ranging from the thick shell middens of the Green River in Kentucky to the shells evenly scattered

throughout the matrix of many Texas sites. The bench deposits lie somewhere toward the latter end of the spectrum. Clusters or light “discard scatters” of shells on buried floodplain surfaces have been found at a number of sites in Texas. Some good examples were found at 41 TR 174, on the West Fork of the Trinity River in Tarrant County. Feature 3 (90 valves, four species), Feature 6 (two clusters 20-25 cm and 40 cm in diameter, 58 valves, three species), and Feature 8 (234 valves, six species) are examples of thin scatters without much other associated debris except some charcoal, baked clay, a few bone fragments, and an occasional hammerstone or debitage (Lintz *et al*. 2004:Figs. 20, 21, 27-29). Three examples ranging from a small cluster to an incipient sheet midden (with shells stacked three or four high) were found at the Gypsum Bluff site in Coke County (Shafer 1971:Fig. 10). A number of examples were found at 41 DL 270 (straddling the Denton County-Dallas County line) including Feature 3 (one to two shells thick, 221 valves, nine species), Feature 9 (1.25 by 1.9 m across, 78 valves, eight species), Feature 10 (0.4 by 1.1 m across, 41 valves, four species), and Feature 29 [1.2 by 1.5 m across, 201 shells, six species (Anthony and Brown 1994:Figs. 54, 55, 58, 59, 64, 74; see also discussion in Anthony 1994)]. Features like these typically contain some fragmentary bone from deer, turtle, or other species, and occasional debitage or tools. They appear to be localized dumps for food remains. The examples mentioned, which range in age from late Middle Holocene to Late Prehistoric, all have greater shell density and species richness than the more sparse scatter in stratum 2A at Berger Bluff, reflecting the higher human population sizes and collecting pressure experienced in the second half of the Holocene. In contrast, I suspect the shell-bearing surface in stratum 2A represents a single collecting event by a small number of people. Ethnographic studies show most shellfish collecting is done by women (Claassen 1998:223; Meehan 1982) and children, and that may well have been the case at Berger Bluff.

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Chapter 10: Vertebrate Fauna

INTRODUCTION AND OVERVIEW

Animal bone from the bench deposits at Berger Bluff is, for the most part, remarkably well preserved, especially in comparison to other sites of similar age. Although most of the bone is mechanically fragmented and complete elements are somewhat uncommon, on the whole it shows limited evidence of chemical dissolution and hardly any of the kind of splitting and cracking to be expected from surface exposure and weathering. Fluvial abrasion also seems to be absent. Figure 10.1 is provided to illustrate just how well-preserved and small some of the elements can be in this assemblage. The specimen is a complete dorsal fin spine from a very small unidentified fish; the bone is reddish-brown, slightly glossy, with no corrosion or etching.

Nearly all the bone from the bench deposits comes from microvertebrates. The largest identifiable bone is a fragment of a raccoon humerus (Fig. 4.57). Otherwise the bone comes from a wide variety of small animals. There are mammals (insectivores, rodents, and lagomorphs, as well as two raccoon elements), amphibians, reptiles (turtles, snakes, lizards), birds, and fish. There are almost no medium or large mammals, and except for a possible specimen of giant tortoise, the largest animal represented is about 13 kg or less in live body weight; most of the animals probably weighed 300-400 g or less. Much of the assemblage represents what I will term a *reclusive fauna*, a collection of small, cryptic, inconspicuous animals. I believe that the animal bone in the bench deposits derives both from cultural and noncultural sources, but the emphasis in this

chapter will mostly be on vertebrates as paleoenvironmental indicators. One osseous artifact (a small polished pin probably made of antler) is present in the collection.

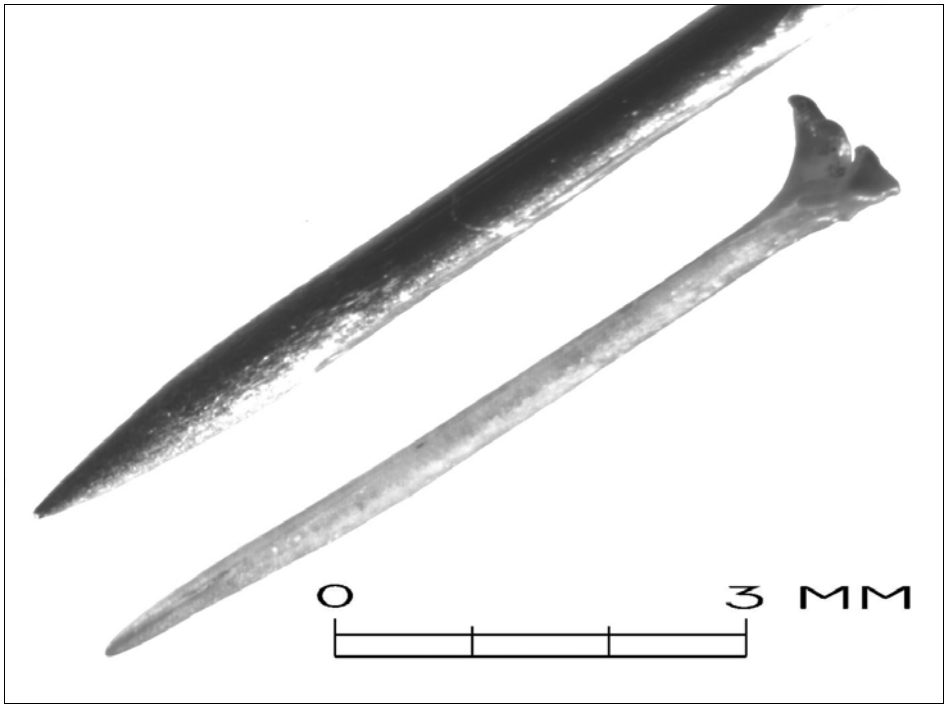

Figure 10.1. Dorsal Fin Spine of Unidentified Fish. This complete fin spine from a very small unidentified minnow, shiner, or darter-sized fish (or juvenile of a larger species) is shown to demonstrate that the best-preserved portion of the bone assemblage is nearly as pristine as fresh bone. The uppermost object is the tip of a common household straight pin, shown for comparison. Ambient bone from coarse fraction of bulk matrix sample, N109 E96 (92.35-92.30 m); articular end at upper right.

With one exception (possible *Gopherus hexagonatus*) there are no known extinct vertebrate species in the bench deposits, but there are several species that are now absent from the local area due to small-scale range shifts and environmental change during the course of the Holocene (Table 10.1). I believe the near absence of extinct species is a function of the size of the animals, not the age of the deposits (although that possibility

should also be considered). Vertebrate extinctions near the end of the Pleistocene were mostly confined to larger animals [none of the disappearing small species listed by Graham and Lundelius (1995:Table 11.1) were present in the catchment area in any case], and these are the taxa that are not present in the bench deposits. The modern vertebrate fauna lacks several species that are present in the bone assemblage from the bench, and there are many species in the modern fauna (mostly larger-sized mammals, birds, fish and snakes) that are not present in the sample from the bench. The same can be said of the vertebrate assemblage from the upper deposits (Flynn 1983:Table 1).

There are two basic categories of bone from the bench deposits:

1) *Ambient bone* is represented by scattered bone fragments distributed thinly throughout the sediments in nearly every area that was sampled. Some of these show evidence of human alteration (heat discoloration or rare cutmarks) and probably have been contributed by human activity, but most probably represent background noise – animals that died on or near the site from natural causes.

2) The *hearth deposit* is a spatially distinct, highly concentrated deposit of microfauna closely associated with Feature 5, a small fire hearth built directly on the floodplain surface (see Chapter 3). The hearth deposit is believed to be entirely the result of human activity and all the bone in it is believed to be cultural in origin. Both categories will be discussed in detail later in this chapter, and I will discuss the possible origin of the deposit at some length, because identifying the responsible predator helps clarify what kinds of biases or filtering mechanisms might have structured the taxonomic composition of the deposit.

Table 10.1. Vertebrate Taxa Recovered From the Bench Deposits.

Taxa Associated With Feature 5 ("Hearth Deposit")

Mammals	
Scalopus aquaticus	Eastern mole
Chaetodipus cf. *C. hispidus*	Pocket mouse, cf. Hispid
Cryptotis parva	Least shrew
Dipodomys cf. *D. compactus* or *D. ordii*	Gulf Coast or Ord's kangaroo rat
Geomys sp. (*G. attwateri* or *G. personatus*)	Pocket gopher, Attwater's or Texas
Sylvilagus sp. (*S. floridanus* or *S. audubonii*)	Cottontail rabbit, eastern or desert
Neotoma sp. (*N. floridana* or *N. micropus*)	Woodrat, eastern or southern Plains
Peromyscus sp. (*P. maniculatus* or *P. leucopus*)	Mouse, deer or white-footed
Onychomys leucogaster	Northern grasshopper mouse
Microtus ochrogaster or *Pitymys pinetorum*	Prairie or pine vole
Amphibians	
Ambystoma texanum	Smallmouthed salamander
Rana cf. *R. berlandieri*	Leopard frog, cf. Rio Grande
cf. Hylidae or Microhylidae	Cricket, chorus, treefrogs, narrowmouth toads
Bufo sp. (*B. americanus* or *B. houstonensis*)	Toad, American or Houston
Snakes	
cf. *Rhinocheilus lecontei*	cf. Longnose snake
Colubrinae	cf. *Diadophis punctatus* [1]
Natricinae	either *Storeria dekayi* or *Virginia striatula* [2]
Viperidae, unidentified	Pit vipers

Lizards, unidentified (small, possibly including subadult *Sceloperus*)

Birds, unidentified passerine, small

Fish
unidentified (small, perch-sized, mature, possibly multiple species)

[Table 10.1 continued on next page]

{Table 10.1, continued from previous page]

Taxa Found Elsewhere in the Bench But Not Represented in the Hearth Deposit

Mammals	
cf. *Lepus californicus*	Black-tailed jackrabbit
Sigmodon hispidus	Hispid cotton rat
Procyon lotor	Raccoon
Unidentified large (deer-sized?) mammal	
Amphibians	
Rana catesbeiana	Bullfrog
Reptiles	
cf. *Gopherus hexagonatus* (?)	Extinct large tortoise (?) [3]
Emydidae	Unidentified cooter or slider
Kinosternidae	Unidentified musk or mud turtle
Nerodia sp.	Water snake, unidentified
Virginia striatula (definite ID)	Rough earth snake
Fish	
Lepisosteus sp.	Gar, species unknown

Notes: Lagomorphs in the hearth and non-hearth samples were identified by different analysts.

[1] The Colubrinae are a subfamily of the Colubridae, small burrowing snakes. There are four vertebrae resembling *Diadophis punctatus*, ringneck snake

[2] The Natricinae are another subfamily of the Colubridae. Two vertebrae resemble either *Storeria dekayi*, Texas brown snake, or *Virginia striatula*, rough earth snake

[3] Tentative identification based on a very small carapace fragment

In the following pages, I will review the modern and Rancholabrean faunas of the surrounding region, discuss some properties that apply to ambient and hearth-related bone alike (weathering, staining, fragmentation and heat alteration), discuss characteristics of the ambient and hearth-related assemblages (taxonomy, estimates of individuals, presence of juveniles, and so forth), and then present species accounts.

CONTEMPORARY LOCAL FAUNA

Baseline ecological assessments of Coleto Creek Reservoir were done in 1975-76. The mammal, amphibian, reptile, and fish species recorded by Espey, Huston & Associates are listed in Tables 10.2, 10.3, and 10.4. There is also a long list of 121 bird species (Espey, Huston & Associates 1976:Table 3-7), but I have not reproduced it here. Altogether, 18 mammal, 33 herpetofaunal, 29 fish, and 121 bird species were recorded, for a total of 201 vertebrate species. However, the pre-inundation studies only lasted about nine months and were mostly limited to land included in the reservoir boundaries. It seems likely that many more than 201 species potentially might occur in the Berger Bluff catchment (which extends upstream well beyond the reservoir limits) or in the foraging radius of any predator based nearby. In an attempt to measure the size and composition of the contemporary local fauna, I have compiled Tables 10.5, 10.6, and 10.7 from published and unpublished literature. These show additional species that were not recorded in the reservoir studies but that might reasonably be expected to occur in the area and either occupy or range into the catchment and surrounding area. "Local" is very loosely defined as Goliad County plus any of the adjoining counties. Because this part of Texas is not especially well sampled, I have been relatively unconservative in admitting species to the lists. As a result of this exercise 31 additional mammal species, 63 additional herpetofaunal species, and 27 additional fish species that are known to occur in the region can be nominated as potential contemporary residents of the catchment area. There are published Christmas bird count lists from the Victoria area that could be used to augment the list of birds as well, and this would probably add a large number of bird species (including migratory species).

Table 10.2. Contemporary Mammals From Coleto Creek Reservoir.

Marsupials	
Didelphis marsupialis	opossum
Insectivores	
Scalopus aquaticus	eastern mole
Cryptotis parva	least shrew
Carnivores	
Procyon lotor	raccoon
Mustela vison	mink
Mephitis mephitis	striped skunk
Urocyon cinereoargenteus	gray fox
Canis latrans	coyote
Rodents	
Sciurus niger	fox squirrel
Geomys bursarius	Plains pocket gopher
Baiomys taylori	Northern pygmy mouse
Peromyscus leucopus	white-footed mouse
Sigmodon hispidus	hispid cotton rat
Myocastor coypus	nutria*
Lagomorphs	
Lepus californicus	Black-tailed jackrabbit
Sylvilagus floridanus	eastern cottontail rabbit
Artiodactyls	
Odocoileus virginianus	white-tailed deer
Xernartha	
Dasypus novemcinctus	nine-banded armadillo**

* Introduced species
** Historic immigrant

Species: 18

Source: Pre-inundation survey, Espey, Huston & Associates (1976:Table 3-14).

Table 10.3. Contemporary Herpetofauna From Coleto Creek Reservoir.

Toads and frogs	
Scaphiopus holbrooki	eastern spadefoot
Acris crepitans	northern cricket frog
Hyla cinerea	green treefrog
Hyla squirella	squirrel treefrog
Hyla versicolor	gray treefrog
Pseudacris streckeri	Strecker's chorus frog
Pseudacris triseriata	striped chorus frog
Bufo valliceps	Gulf coast toad
Rana catesbeiana	bullfrog
Rana utricularia	southern leopard frog [= *R. sphenocephala*?]
Gastrophryne olivacea	Great Plains narrowmouth toad
Turtles	
Kinosternon subrubrum	eastern mud turtle
Trachemys scripta	red-eared slider [=*Chrysemys scripta*]
Terrapene carolina	eastern box turtle
Terrapene ornata	western box turtle
Trionyx sp.	softshell turtles*
Anoles, lizards and snakes	
Anolis carolinensis	green anole
Sceloporus olivaceus	Texas spiny lizard
Sceloporus undulatus	northern fence lizard
Scincella lateralis	ground skink [= *Leiolopisma laterale*]
Cnemidophorus sexlineatus	six-lined racerunner
Coluber constrictor	racer
Elaphe obsoleta	rat snake
Heterodon platyrhinos	eastern hognose snake
Lampropeltis calligaster	prairie kingsnake
Masticophis flagellum	coachwhip
Nerodia erythrogaster	blotched water snake [=*Natrix erythrogaster*]
Nerodia fasciata	broad-banded water snake [=*Natrix fasciata*]
Nerodia rhombifera	diamondback water snake [=*Natrix rhombifera*]
Opheodrys aestivus	rough green snake
Pituophis melanoleucus	bullsnake
Thamnophis proximus	western ribbon snake
Agkistrodon piscivorus	cottonmouth

Species: 33

* Probably *Trionyx spiniferus guadalupensis* (Guadalupe spiny softshell)
Source: Pre-inundation survey, Espey, Huston & Associates (1976:Table 3-6)

Table 10.4. Contemporary (Pre-Inundation) Fish From Coleto Creek.

Cyprinidae	
Campostoma anomalum	central stoneroller
Cyprinella lutrensis [=*Notropis lutrensis*]	red shiner
Cyprinella venusta [=*Notropis venustus*]	blacktail shiner
Notropis buchanani	ghost shiner
Notropis stramineus	sand shiner
Opsopoeodus emiliae [=*Notropis emiliae*]	pugnose minnow
Pimephales vigilax	bullhead minnow
Catostomidae	
Carpiodes carpio	river carpsucker
Ictiobus bubalus	smallmouth buffalo
Ictaluridae	
Ictalurus punctatus	channel catfish
Noturus gyrinus	tadpole madtom
Cyprinodontidae	
Cyprinodon variegatus	sheepshead minnow*
Fundulus olivaceus	blackspotted topminnow
Poeciliidae	
Gambusia affinis	western mosquitofish
Poecilia latipinna	sailfin molly*
Atherinidae	
Menidia beryllina	inland silverside*
Mugilidae	
Mugil cephalus	striped mullet*

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[Table 10.4, continued from previous page]

Centrarchidae	
Lepomis auritus	redbreast sunfish**
Lepomis cyanellus	green sunfish
Lepomis gulosus	warmouth
Lepomis humilis	orangespotted sunfish
Lepomis macrochirus	bluegill
Lepomis megalotis	longear sunfish
Lepomis microlophus	redear sunfish
Lepomis punctatus	spotted sunfish
Micropterus punctulatus	spotted bass
Pomoxis annularis	white crappie
Cichlidae	
Cichlasoma cyanoguttatum	Rio Grande cichlid**
Percidae	
Etheostoma gracile	slough darter

Species: 29

* Estuarine or brackish water species.
** Locally introduced species.

Source: Pre-inundation survey (Murray, Jinnette and Moseley 1976:Tables 16-19).
Current taxonomy is used; names in brackets are those from the original source.

The Christmas bird counts for Victoria for 1978-1997 have a mean of about 115 species (range, 91-159; source: American Birds, 1978-93, National Audubon Society Field Notes, 1994-97). Table 10.8 summarizes the numbers and suggests that the contemporary local fauna includes well over 319 vertebrate species. Birds represent about 38% of the species (and would rank even higher if regional bird counts had been included), herpetofauna accounts for 29%, fish 18%, and mammals 15% of the species. For the Guadalupe Delta Wildlife Management Area, 308 bird species have been recorded (Texas Parks and Wildlife n. d.).

If vertebrate species richness was comparable or even higher during the Younger Dryas and early Holocene, there may well have been some 300-350 vertebrate species locally present, especially if extinct species or species with known range shifts are also considered. Table 10.9 lists a dozen and a half extinct species (mostly mammals) that might possibly have been present during the Younger Dryas. The list is generalized from paleontological research throughout Texas, since very little is known about terminal Pleistocene faunas in the immediate area (the number of horse species is uncertain, but there were apparently several). The list is short because most Pleistocene extinctions occurred by about 11,400-10,800 RCYBP according to Fiedel and Haynes (2004:123-124) or by 10,400 RCYBP according to Beck (1996:Appendix). Cuban sloths and dwarfed mammoths on Wrangel Island and the Channel Islands in the Pacific are exceptions surviving well onto the Holocene. Table 10.10 shows some of the presumed Rancholabrean faunas that have actually been recovered in nearby areas (all lack chronometric control). Only one of the extinct species on this list has been found at Berger Bluff, but they clearly were present in the area at some time in the past.

The species list from the bench deposits (Table 10.1) indicates there are at least 30 species present in the archeological sample (and probably more, but with uncertainty resulting from difficulty in identification). If there were about 350 vertebrate species present in the local area in the Younger Dryas, then these 30 or more species represent a sample of only about 9% of the local vertebrates. The conclusion that this represents a very *incomplete* sample of the regional vertebrate fauna is inescapable; but is it also a *biased* sample? It is indisputably size-biased, since the animals are nearly all microvertebrates, but is it also biased with respect to the habitats in which the animals originated? I will discuss these topics in some detail as this chapter unfolds.

Table 10.5. Additional Regionally Recorded Mammals.

Note: below are listed animals recorded not in the pre-inundation baseline survey, but in the surrounding counties, and that might reasonably be expected to occur in the area (based chiefly on Schmidly 2004). Extinct, domestic, and introduced species are not included.

Blarina carolinensis	southern short-tailed shrew
Pipistrellus subflavus	eastern pipistrelle
Lasiurus borealis	eastern red bat
Lasiurus cinereus	hoary bat
Lasiurus intermedius	northern yellow bat
Nycticeius humeralis	evening bat
Tadarida brasiliensis	Brazilian free-tailed bat
Spermophilus tridecemlineatus	thirteen-lined ground squirrel
Geomys attwateri	Attwater's pocket gopher
Perognathus merriami	Merriam's pocket mouse
Sciurus carolinensis	eastern gray squirrel
Chaetodipus hispidus	hispid pocket mouse
Dipodomys compactus	Gulf coast kangaroo rat
Reithrodontomys fulvescens	fulvous harvest mouse
Peromyscus maniculatus	deer mouse
Onychomys leucogaster	northern grasshopper mouse
Neotoma floridana	eastern woodrat
Neotoma micropus	southern Plains woodrat
Canis rufus	red wolf
Bassariscus astutus	ringtail
Mustela frenata	long-tailed weasel
Mustela vison	mink
Taxidea taxus	badger
Spilogale putorius	eastern spotted skunk
Conepatus leuconotus	eastern hog-nosed skunk
Lutra canadensis	river otter
Felis concolor	mountain lion
Lynx rufus	bobcat
Tayassu tajacu	collared peccary
Antilocapra americana	pronghorn
Bison bison	bison

Species: 31

Table 10.6. Additional Regionally Recorded Herpetofauna.

Note: below are herpetofauna recorded not in the pre-inundation baseline survey, but in the surrounding counties, and that might reasonably be expected to occur in the area (based chiefly on Dixon 1987 and Werler and Dixon 2000).

Siren intermedia nettingi	western lesser siren
Ambystoma texanum	smallmouth salamander
Ambystoma tigrinum tigrinum	eastern tiger salamander
Notophthalmus meridionalis	black-spotted newt
Notophthalmus viridescens louisianensis	central newt
Hypopachus variolosus	sheep frog
Scaphiopus couchi	Couch's spadefoot
Pseudacris clarki	spotted chorus frog
Bufo debilis debilis	eastern green toad
Bufo speciosus	Texas toad
Bufo woodhousei velatus	Woodhouse's toad
Rana berlandieri	Rio Grande leopard frog
Gastrophryne carolinensis	eastern narrowmouth toad
Alligator mississippiensis	alligator
Chelydra serpentina serpentina	common snapping turtle
Kinosternon flavescens flavescens	yellow mud turtle
Graptemys caglei	Cagle's map turtle
Pseudemys texana	Texas river cooter
Gopherus berlandieri	Texas tortoise
Alligator mississippiensis	American alligator
Holbrookia lacerata subcaudalis	southern earless lizard
Holbrookia propinqua propinqua	keeled earless lizard
Phrynosoma cornutum	Texas horned lizard
Sceloporus variabilis marmoratus	rosebelly lizard
Eumeces fasciatus	five-lined skink
Eumeces laticeps	broadhead skink
Eumeces septrionalis obtusirostris	southern prairie skink
Cnemidophorus gularis gularis	Texas spotted whiptail
Ophisaurus attenuatus	western slender glass lizard
Leptotyphlops dulcis dulcis	Plains blind snake
Leptotyphlops dulcis dissectus	New Mexico blind snake
Arizona elegans arenicola	Texas glossy snake
Arizona elegans elegans	Kansas glossy snake
Arizona elegans philipi	painted desert glossy snake
Coluber constrictor anthicus	buttermilk racer
Coluber constrictor etheridgei	tan racer
Coluber constrictor flaviventris	eastern yellow-bellied racer
Coluber constrictor oaxaca	Mexican racer

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[Table 10.6, continued from previous page]

Coluber constrictor priapus	southern black racer
Drymarchon corais erebennus	Texas indigo snake
Elaphe guttata guttata	corn snake
Elaphe guttata emoryi	Great Plains rat snake
Elaphe guttata meahllmorum	southwestern rat snake
Elaphe obsoleta lindheimeri	Texas rat snake
Farancia abacura reinwardti	western mud snake
Heterodon nasicus gloydi	dusky hognose snake
Heterodon platirhinos	eastern hog-nosed snake
Lampropeltis calligaster calligaster	prairie king snake
Lampropeltis getula splendida	desert king snake
Lampropeltis getula holbrooki	speckled king snake
Masticophis flagellum flagellum	eastern coachwhip
Masticophis flagellum testaceus	western coachwhip
Masticophis schotti ruthveni	Ruthven's whipsnake
Masticophis taeniatus schotti	Schott's whipsnake
Nerodia erythrogaster flavigaster	yellow-bellied water snake
Nerodia erythrogaster transversa	blotched water snake
Nerodia fasciata confluens	broad-banded water snake
Nerodia rhombifer rhombifer	diamond-backed water snake
Opheodrys aestivus	rough green snake
Pituophis catenifer sayi	bull snake
Regina grahami	Graham's crayfish snake
Rhinocheilus lecontei tessellatus	Texas longnose snake
Salvadora grahamiae lineata	Texas patchnose snake
Storeria dekayi limnetes	marsh brown snake
Storeria dekayi texana	Texas brown snake
Tantilla gracilis	flat-headed snake
Tantilla nigriceps fumiceps	Texas blackhead snake
Thamnophis marcianus marcianus	checkered garter snake
Thamnophis proximus diabolicus	arid land ribbon snake
Thamnophis proximus proximus	western ribbon snake
Thamnophis proximus orarius	Gulf coast ribbon snake
Thamnophis proximus rubrilineatus	red-striped ribbon snake
Thamnophis sirtalis sirtalis	eastern garter snake
Tropidoclonion lineatum	lined snake
Virginia striatula	rough earth snake
Micrurus fulvus tener	Texas coral snake
Agkistrodon contortrix contortrix	southern copperhead
Agkistrodon contortrix laticinctus	broad-banded copperhead
Crotalus atrox	western diamondback rattlesnake
Crotalus horridus atricaudatus	canebrake rattlesnake

Species: 61
Species + subspecies: 80

Table 10.7. Additional Regionally Recorded Fish.

Note: below are additional fish species recorded from the Guadalupe River at Victoria and Seguin (1949-1989) in surveys commissioned by Dupont, species that conceivably could have been found in the lower part of Coleto Creek, or could have been obtained by a wide-ranging predator. Because they are part of the regional fauna, they are listed here.

Ambloplites rupestris	rock bass**
Ameiurus natalis [=*Ictalurus natalis*]	yellow bullhead
Anchoa mitchilli	bay anchovy*
Astyanax mexicanus	Mexican tetra**
Atractosteus spatula [=*Lepisosteus spatula*]	alligator gar
Cyprinus carpio	common carp**
Dorosoma cepedianum	gizzard shad*
Dorosoma petenense	threadfin shad
Etheostoma chlorosomum	bluntnose darter
Fundulus chrysotus	golden topminnow
Fundulus notatus	blackstripe topminnow
Gobionellus boleosoma	freshwater goby, darter goby*
Ictalurus furcatus	blue catfish
Lepisosteus oculatus	spotted gar
Macrhybopsis aestivalis [=*Hybopsis aestivalis*]	speckled chub
Micropterus salmoides	largemouth bass
Micropterus treculi	Guadalupe bass
Morone chrysops	white bass
Moxostoma congestum	gray redhorse
Notemigonus crysoleucas	golden shiner
Notropis amabilis	Texas shiner
Notropis volucellus	mimic shiner
Percina carbonaria [= *P. caprodes carbonaria*]	Texas logperch
Percina macrolepida	bigscale logperch
Pomoxis nigromaculatus	black crappie
Pylodictis olivaris	flathead catfish
Trinectes maculatus	hogchoker*

Species: 27

* Estuarine or brackish water species.
** Locally introduced species.

Source: Academy of Natural Sciences of Philadelphia (1991:Table V-2). Current taxonomy is used; names in brackets are those from the original source.

Table 10.8. Species Richness of Contemporary Vertebrate Fauna.

Species recorded in pre-inundation studies

	Number of species	Table
mammals	18	10.2
herpetofauna	33	10.3
fish	29	10.4
birds	121	not listed
subtotal:	201	

Additional regionally recorded species

	Number of species	Table
mammals	31	10.5
herptetofauna	61	10.6
fish	27	10.7
birds	?	not listed
subtotal:	119+	
grand total:	320+	

Table 10.9. Extinct Species Potentially Present in the Region.

Bison antiquus	extinct bison
Camelops hesternus	yesterday's camel
Canis dirus	dire wolf
Coragyps occidentalis	western vulture
Dasypus bellus	giant armadillo
Equus spp.	several species of extinct horse
Geochelone crassiscutata?	giant tortoise
Geochelone wilsoni	Wilson's tortoise
Geococcyx californicus conklingi	extinct roadrunner
Gopherus hexagonatus	extinct tortoise
Mammut americanum	American mastodont
Mammuthus columbi	Columbian mammoth
Megalonyx jeffersonii?	Jefferson's ground sloth
Panthera leo atrox	American lion
Paramylodon harlani	Harlan's ground sloth
Platygonus compressus	flat-headed peccary
Smilodon fatalis	saber-toothed tiger
Tapirus veroensis	Vero tapir

Parameters for listing:

1. Extinct species
2. Not yet extinct at 11,000-10,000 RCYBP
3. Plausibly present on central Gulf coastal plain

Table 10.10. Fossil Species From Nearby Undated Rancholabrean Sites.

Morhiss Site (Victoria County)	
Alligator sp.	alligator
Antilocapra sp.	antelopes, unidentified
Bison sp.	bison, unidentified
Camelops sp.	camel, unidentified
Chelonia (order)	turtles, unidentified
Equus sp.	extinct horse, unidentified
Geochelone sp.	extinct tortoise, unidentified
Hemiauchenia sp.	extinct llama, unidentified
Mammuthus sp.	mammoth, unidentified
Odocoileus sp.	deer, presumably white-tailed
Ursus sp.	bear, unidentified
Weesache (Goliad County; Welsch collection, see Chapter 1)	
Bison antiquus	extinct bison (Fig. 1.21)
Geochelone sp.?	extinct tortoise?
Buckner Ranch (Bee County)*	
Alligator sp.	alligator
Anura	frogs/toads, unidentified
Bison sp.	bison, unidentified
Blastomeryx sp.	extinct deer
Camelidae	camel, unidentified
Carnivora	carnivore, unidentified
Chelonia (order)	turtles, unidentified
Equus sp.	extinct horse, unidentified
*Geochelone/Gopherus***	tortoise, unidentified
Geomys sp.	pocket gopher, unidentified
Glyptotherium floridanus	Simpson's glyptodont
Holmesina sp.	pampathere, undoubtedly *H. septentrionalis*
Lepus sp.	jackrabbit, unidentified
Mammuthus columbi	Columbian mammoth
Mammutidae	mastodonts, unidentified
Meleagris gallopavo	turkey
Ondatra zibethicus	muskrat
Scalopus aquaticus texanus	eastern mole
Serpentes	snakes, unidentified
Sigmodon hispidus	hispid cotton rat

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[Table 10.10, continued from previous page]

Buckner Ranch 3 (Bee County)	
Bison sp.	bison, unidentified
Chelonia (order)	turtles, unidentified
Equus sp.	extinct horse, unidentified
Holmesina sp.	pampathere, unidentified
Mammuthus columbi	Columbian mammoth
Rodentia	rodents, unidentified
Testudinidae	tortoises, unidentified
Xenartha	armadillos and sloths
Dan Fox Ranch (Bee County)	
Mammuthus sp.	mammoth, unidentified
Heard Ranch (Bee County)	
Bison sp.	bison, unidentified
Equus complicatus	extinct horse
Testudo sp.	
Lucas Ranch (Bee County)	
Equus sp.	extinct horse, unidentified
Mammuthus sp.	mammoth, unidentified
Odocoileus sp.	deer, presumably white-tailed
Osteichthyes	fish, unidentified
Protolabis sp.***	(pre-Rancholabrean camel)
Pseudemys/Trachemys sp.	cooter/slider turtle, unidentified
Rodentia	unidentified rodents
Sylvilagus sp.	unidentified rabbits
Trionyx sp.	softshell turtle, unidentified
Medio Creek (Bee County)	
Bison sp.	bison, unidentified
Carnivora	unidentified carnivores
Chelonia (order)	turtles, unidentified
Elephantidae	mammoths, unidentified
Equus sp.	extinct horse, unidentified
Mammut sp.	mastodon
Nannippus sp.***	(pre-Rancholabrean horse)
Odocoileus sp.	deer, presumably white-tailed
Rodentia	rodents, unidentified
O'Brian Ranch (Bee County)	
Alligator sp.	alligator
Antilocapridae	antelopes, unidentified
Bison sp.	bison, unidentified
Camelops sp.	camel, unidentified

[continued on next page]

[Table 10.10, continued from previous page]

Capromeryx minor	pronghorn, small extinct
Cricetidae	cricetid rodents, unidentified
Dasypus bellus	extinct beautiful armadillo
Equus sp.	extinct horse, unidentified
Glyptotherium floridanus	Simpson's glyptodont
Mammuthus sp.	mammoth, unidentified
Osteichthyes	fish, unidentified
Testudinidae	tortoises, unidentified

Powers Ranch (Bee County)

Bison sp.	bison, unidentified
Camelidae	camel, unidentified
Carnivora	unidentified carnivores
Chelonia (order)	turtles, unidentified
Equus altidens	Troxell's stilt-legged horse
Equus leidyi	extinct horse
Geochelone sp.	extinct tortoise, unidentified
Glyptotherium floridanus	Simpson's glyptodont
Hemiauchenia sp.	extinct llama, species unidentified
Lepisosteus sp.	gar, unidentified
Pseudemys/Trachemys sp.	cooter/slider turtle, unidentified
Trionyx sp.	softshell turtle, unidentified

Cove Harbor (Aransas County)

Alligator mississippiensis	alligator
Amiidae	bowfin, unidentified
Aves	birds, unidentified
Bison sp.	bison, unidentified
Camelidae	camel, unidentified
Equus sp.	extinct horse, unidentified
Geomyidae	pocket gophers, unidentified
Glyptotherium floridanus	Simpson's glyptodont
Lepisoteidae	gar, unidentified
Leporidae	rabbits and hares, unidentified
Mammut americanum	mastodont
Myliobatidae	unidentified ray (marine)
Odocoileus sp.	deer, presumably white-tailed
Osteichthyes	fish, unidentified
Platygonus sp.	flat-headed peccary
Pseudemys/Trachemys sp.	cooter/slider turtle, unidentified
Rodentia	rodents, unidentified
Scalopus sp.	mole, presumably *Scalopus aquaticus*
Serpentes	snakes, unidentified

[continued on next page]

[Table 10.10, continued from previous page]

Terrapene sp.	box turtles, unidentified
Trionyx sp.	softshell turtle, unidentified
Xenartha	armadillos and sloths
Nobles Point (Calhoun County)	
Alligator sp.	alligator
Anura	frogs/toads, unidentified
Bison sp.	bison, unidentified
Camelops sp.	camel, unidentified
Cuvierionus sp.	extinct gomphothere
Emydidae	water and box turtles, unidentified
Equus sp.	extinct horse, unidentified
Eremotherium sp.	extinct megathere
Glyptotherium floridanus	Simpson's glyptodont
Holmesina sp.	pampathere, unidentified
Lepisosteus sp.	gar, unidentified
Odocoileus sp.	deer, presumably white-tailed
Serpentes	snakes, unidentified
Tanupolama sp.	llama-like camel
DeWitt County (unspecified locality)	
Mammuthus sp. (skull)	mammoth, unidentified
Fred Dubose Farm (Gonzales County)	
Bison sp.	bison, unidentified
Chelonia (order)	turtles, unidentified
Mylodontidae	extinct sloth
Dreyer Farm (Gonzales County)	
Mammuthus sp.	mammoth, unidentified
Guadalupe River (Guadalupe County)	
Mammut americanum (molar)	mastodon
Seguin (Guadalupe County)	
Mammuthus sp.	mammoth, unidentified

* This site also has an extensive fauna of Clarendonian age from the Goliad Formation; see also Nash (2001).
** Moodie and VanDevender (1979) list this as *Geochelone wilsoni*.
*** An earlier fossil, not part of the Rancholabrean fauna.

Source: TMM online vertebrate paleontology database, except as noted.

The position taken here is much like that summarized by Edward Deevey:

> In the creative restoration that follows paleoecological field work, the ecosystem must be fleshed out to some degree by analogy with modern counterparts. Any organization, especially any nonobvious organization, that is discerned in the restored system may therefore have been put there by the observer. It is not surprising that paleoecologists generally refrain from asking quantitative or synecological questions and concentrate on the autecologies of species they can see (Deevey 1969:225).

THE TEXAN/TAMAULIPAN BOUNDARY

Berger Bluff lies on the boundary between the contemporary Texan biotic province to the northeast and the Tamaulipan biotic province to the southwest (Presley 2003:Figs. 2, 6). In reality, these biotic provinces are large-scale macroecological zones that have little in the way of visible physiographic expression. The major vegetation zones run southwest to northeast and cut through the boundary without stopping (Fig. 1.17). Annual precipitation isoclines run mostly north-south and do not correspond to the boundary. Likewise, temperature isotherms are irregular and do not correspond very well. Despite this lack of expression, there seem to be several definite examples of parapatric species distributions along the boundary between the Texan and Tamaulipan biotic zones. *Parapatric distributions* are ones in which pairs of taxa have separate but adjoining distributions, with no more than a narrow zone of overlap in between (Bull 1991; Dalbey 1980). For example, the area lies on or near the parapatric range boundaries between the eastern woodrat (*Neotoma floridana*), Attwater's pocket gopher (*Geomys attwateri*), and thirteen-lined ground squirrel (*Spermophilus tridecemlineatus*) in the Texan province, and the southern Plains woodrat (*Neotoma micropus*), Texas pocket gopher (*Geomys personatus*), and Mexican ground squirrel (*Spermophilus mexicanus*) in the Tamaulipan province (although the gopher boundaries actually overlap in Bee, Goliad, and Karnes

County; Schmidly 2004:331, 340). These boundaries likely have shifted constantly northeast or southwest during the Quaternary in response to the vagaries of climatic and floristic change. The site lies in post oak parkland (Figs. 1.17, 1.22), although coastal prairie can be found less than 5 km away (Fig. 1.17). Many of the typical neotropical taxa characteristic of the Tamaulipan zone (Presley 2003:Table 1) are absent from this area.

There are also several examples of Texan species whose range appears limited at the southern end by the Texan/Tamaulipan boundary, but without matching Tamaulipan species: the smallmouth salamander (*Ambystoma texanum*), eastern narrowmouth toad (*Gastrophryne carolinensis*), three-toed box turtle (*Terrapene carolina triunguis*), broadhead skink (*Eumeces laticeps*), southern prairie skink (*Eumeces septentrionalis obtusirostris*), swamp rabbit (*Sylvilagus aquaticus*), eastern gray squirrel (*Sciurus carolinensis*), red fox (*Vulpes vulpes*, an introduced species), mink (*Mustela vison*). These species cannot be considered parapatric, but they might be environmental indicator species nevertheless.

There are also a significant number of herpetofaunal species whose northern limits stop at or near the boundary with the Texan biotic province in this immediate area: the eastern green toad (*Bufo debilis debilis*), Rio Grande leopard frog (*Rana berlandieri*), southern earless lizard (*Holbrookia lacerata subcaudalis*), keeled earless lizard (*Holbrookia propinqua propinqua*), rosebelly lizard (*Sceloporus variabilis marmoratus*), Texas indigo snake (*Drymarchon corais erebennus*), and Schott's whipsnake (*Masticophus taeniatus schotti*) may be examples. Not all of these are confined to the Tamaulipan province, but at least in this area of the state, they seemed to be limited by the boundary with the Texan province.

The number of species responding to the boundary between these two major biotic provinces suggests it might have some environmental significance, and its position has probably shifted along a southwest-northeast axis throughout the Quaternary in response to climatic developments.

SPECIES RICHNESS COMPARED TO OTHER LATE RANCHOLABREAN SITES

If other archeological and paleontological sites of similar or slightly greater age in Texas are examined, it is clear that the number of species recovered depends on a wide variety of factors – the concentration of bone in the sediments, the amount of fill processed to recover bone, the condition of the bone after burial, and the processes that contributed bone to the sediments at the outset (fluvial deposition, on-site death, raptor pellet deposits, and so forth). Table 10.11 lists several archeological and paleontological components of late Wisconsinan to early Holocene age, as well as a few local sites of later Holocene age. Hall's Cave, Cueva Quebrada, Bonfire Shelter, and the Aubrey and Driscoll sites are all considerably older than the bench deposits at Berger Bluff; Zesch Cave is undated. The numbers shown in Table 10.11 are *minimum numbers of species*. For example, if a site has produced "Osteichthyes, unidentified," then it can only be said that there is at least one species of fish present at the site, and a "1" is entered in the fish column. There were probably at least two or three species of horse present regionally at the end of the Rancholabrean Land Mammal Age (Baskin and Mosqueda 2002), but the actual number is uncertain.

Table 10.11 shows several things:

- Berger Bluff has neither the longest nor the shortest species list, but is somewhere in the middle
- Fish and birds are especially underrepresented at all kinds of sites, although the number of waterfowl at Lubbock Lake is impressive
- None of the sites appears to even approach a complete sampling of the spectrum of species that probably existed in their respective regions when the faunas were accumulating in the sites

The numbers of species at these sites vary widely, and it is clear that there is no single cause. Lubbock Lake probably leads the list because fieldwork was extensive, and special attention was paid to recovery of microvertebrate and other faunal material. The Armstrong and Richard Beene sites probably have few species because of poor preservation. And for nearly all sites where predation (either human or nonhuman) was involved, most likely only part of the faunal spectrum is documented because predation was rather highly targeted, and not overly opportunistic. I suspect the lack of fish and birds has more to do with lack of sampling by predators and less with taphonomic decay.

Zooarcheologists often seem to have less expertise or interest in fish and bird remains, and that may lead to taxonomic deflation for these groups as well. Sinkhole and cave sites like Hall's Cave and Zesch Cave often produce high species counts because they are raptor roosts or carnivore dens that tend to concentrate faunal remains. Sites like this can record a fairly complete roster of the local mammal fauna, at least (Hadly 1999). In addition to these considerations, the species counts are probably significantly inflated because of time-averaging. Most of these components probably represent slices of time that are at least a couple of thousand years long.

Table 10.11. Vertebrate Minimum Species Richness for Various Archeological and Paleontological Sites.

Site	Minimum Number of Species Present				
	Fish	Birds	Herpetofauna	Mammals	Total
Paleoindian archeological components					
Lubbock Lake [1]	10	34	38	42	124
Aubrey (all loci) [2]	7	4	10	24	45
Driscoll [3]	7	2	9	24	42
Wilson-Leonard (strat I, II)[4]	2	1	10	20	33
Berger Bluff bench	2	1	14	14	31
Levi Rockshelter [5]	1	0	3	22?	26?
Cueva Quebrada [6]	?	?	?	23	?
Buckner Ranch [7]	0	1	5	14*	20
Kincaid Shelter (zones 2-4) [8]	0	2?	4	12	18?
Richard Beene [9]	1	1	5	11	18
Gault (Clovis component) [10]	0	1	1	8	10
Armstrong [11]	0	0	1	5	6
Bonfire Shelter [12]	0	0	0	6	6
Lake Theo [13]	0	0	1	5?	5?
Holocene (Archaic/Late Prehistoric) archeological components					
Berger Bluff, upper [14]	3	8	13	22**	46
Burris [15]	1	2	5	8	16
Paleontological components					
Hall's Cave [16]	5	19?	21?	61?	106?
Zesch Cave [17]	0	9	10	46?	65?

* Includes *Capromeryx*, although TMM database lists it as deriving from Goliad Fm.
* * Includes sheep/goat, European pig, javelina.

Note: numbers given are minimum numbers of species. In most cases, the actual number of species is probably significantly higher due to identification difficulties.

[Table 10.11 footnotes continued on next page]

[Table 10.11, continued from previous page]

Sources:

1. Johnson (1987:Table 7.1, Paleoindian components only)
2. Yates and Lundelius (2001:Tables 8.1, 8.3)
3. Lewis (n.d., Table 1)
4. Balinsky (1998:Tables 35-2, 35-3); Bousman (1998:Tables 8-19, 8-20)
5. Alexander (1963:Table 1)
6. Lundelius (1984)
7. Nash (2001:Appendix 3) and TMM database
8. Winans (n.d.)
9. Baker and Steele (1992:Table 1, Paleoindian components only)
10. Cinda Timperley (2005, personal communication)
11. Johnson, Baxevanis and Willett (2002:Table 1)
12. Bement (1986)
13. Harrison and Killen (1978:Tables 3, 4)
14. Flynn (1983:Table 21)
15. Shaffer (n.d., Table 1)
16. Toomey (1993:Table 11)
17. Sagebiel (1998)

HISTORY OF COLLECTION AND IDENTIFICATION

In order to understand the nature of the animal bone collection from the bench deposits, it is critical to understand something of the history of its collection and study. After completion of the excavations in April, 1980, individual bone specimens that had been found in place or on the field screens were returned to the UTSA-CAR archeology lab for cataloging. Dozens of plastic tube bags (Fig. 3.9) containing about a cubic meter of fill that been collected underneath the 1/4-inch screen from unit N109 E96 had already been delivered to the Vertebrate Paleontology lab at the University of Texas at Austin for processing. In 1982, the cataloged specimens were identified by Boyce Cabaniss, then a graduate student in vertebrate paleontology, using the comparative collections at the VP lab. Cabaniss also washed down the matrix from N109 E96 through nested coarse and fine mesh screens. There are no lab notes from the washing process, and since I was in San Antonio at the time, I did not observe the screenwashing. The mesh size was not recorded anywhere, but the coarse mesh is believed to be 1/8-inch and the fine mesh is undoubtedly window screen. Cabaniss also screenwashed some smaller lots of matrix from Unit 2, the cutbank profile in stratum 2A, and a very important bag of fill from N113 E98 (92.40 to approximately 92.35 m, lot B-107A) which later proved to contain bone from the hearth deposit. After washing down the samples and drying the residue, Cabaniss began trial picking of some lots, and reported that the residue was so unproductive that it was not worth picking. This was very disappointing, and after Cabaniss abandoned picking efforts, the residue was then put in storage in the VP lab, where it was to stay for several years.

In 1982, Cabaniss identified the *in situ* and 1/4-inch screen specimens (over 3200 specimens; Table 10.12), and prepared an inventory. In 1987 I began to photograph the bone for eventual publication, but since the identifications were recorded in the inventory but not, in every case, on the provenience tags, in the summer of 1987 I enlisted the help of Alisa J. Winkler, then a graduate student in vertebrate paleontology at Southern Methodist University, to select specimens for photography, re-identifying them when more than one specimen was present in a vial, and recording the correct anatomical orientation. During this process nearly every fragment was re-examined and the original identification checked. The result was that the original identification was found to be very accurate. Very few errors in identifications were found, and these were very minor in nature. In addition, several small bits of bone that had never been identified were located. These, along with some previously considered unidentifiable, were identified by Winkler, using the Shuler Museum comparative collection. No new taxa were added, but the element count was increased. Winkler also assisted by computing MNIs (Minimum Numbers of Individuals). Cabaniss and Winkler were both supported by a grant from the Texas Archaeological Foundation awarded to me in 1982. They were selected as consultants specifically because of their familiarity with microvertebrates.

In 1988 and 1989, the herpetofauna (including turtle material) from the identified material was pulled and sent to the late Bill McClure (1927-2002) of Houston, Texas, for further identification. McClure, an amateur herpetologist and osteologist with a comprehensive personal reference collection, was a recognized expert with extensive experience in Texas zooarcheology. He was able to refine the identifications and add several previously unrecognized taxa to the species list. His results were reported in

1989, with a few additional identifications reported in 1991, and the herpetofaunal material was returned to me.

Table 10.12. Specimen Counts (NISP) for Major Categories of Bone.

	Analyzed	Not Yet Analyzed
Ambient Bone (N = 2560)		
1/4-inch screen (cutbank, all units except Unit 2)	462	-----
N109 E96, bulk matrix, coarse fraction, 8 levels*	125	1986
Hearth Deposit (N = 4102)		
Unit 2 (lot B-149)	44	-----
N113 E98 (lots B-105, B-106, B-107)	2909	-----
N113 E98 matrix sample (ca. 92.40-92.35)	------	1188
Subtotals:	3540	3174
Grand total: 6714		

* 13 more levels remain unpicked and will probably produce additional bone.
Note: conjoinable fragments with fresh breaks are counted as one specimen.

In summary, Cabaniss and Winkler examined and identified all the cataloged material, McClure provided further identifications of herpetofauna, and Winkler did most of the MNI calculations. I typed up the specimen inventory, measured samples of the bone fragments, made some observations on whether bone breakage was pre-excavation or excavation-related, did a color analysis of some bone samples, and recorded some

more detailed observations on fish vertebrae and turtle shell. In 1990, I did an X-ray analysis of growth rings in some of the fish vertebrae from the bench deposits (Brown 1990) as part of a course in vertebrate biostratigraphy with Dr. Ernest Lundelius.

At some time during this period, Lundelius notified me that the screenwashed residue which had been in storage for several years in the VP lab was about to be discarded and asked if I wanted to have it returned. I took possession, began to pick some of the material, and discovered that Cabaniss's assessment of the material's potential several years earlier had been unduly pessimistic. There was perhaps enough bone material to justify the considerable picking effort, and the residue also yielded very large quantities of microsnails (including new specimens of *Valvata* and *Cincinnatia*) along with occasional cultural debris (microflakes), hackberry seeds, and other items of interest. I selected eight excavation levels from N109 E96 for complete picking and spent several hundred hours picking the residue over the next couple of years. Levels were selected so as to provide a good representation from the bottom, middle, and top of the stratigraphic section; this effort produced an additional 1986 specimens that have not yet been analyzed. A single lot from N113 E98 (92.40 to approximately 92.35 m, lot B-107A) produced another 1188 specimens, also not yet analyzed (Table 10.12). In 1992, all of the residue was inventoried and repackaged.

PROVENIENCE CATEGORIES AND RECOVERY METHODS

Ambient Bone

Ambient bone is believed to represent an assortment of bone from animals that died naturally on the site, animals that were introduced by human agency, and

conceivably occasional fragments that may have been introduced as clastic material by flooding or sheetwash, although there is no clear physical evidence for this in the form of fluvial abrasion. In some cases small clusters of a few bone fragments were found associated with debris (charcoal, chipping debris, mussel shells) that was clearly cultural in nature, suggesting at least some of the ambient bone is of cultural origin, but there are no dense concentrations comparable to the hearth deposit. Ambient bone was recovered by several methods:

1) Fragments found on the 1/4-inch screen; some of these are smaller than 1/4 inch in length, because some were found atop sediment trapped by the screen;

2) Fragments found and plotted in place (these are rare);

3) Fragments recovered from the two matrix columns (N109 E103 and N110 E102) that were processed for grain-size analysis (each column was only about 25 x 25 cm in horizontal extent, so the number of specimens is small);

4) In unit N109 E96 only, fragments recovered by fine-mesh sieving of the bulk matrix passing the 1/4-inch screen. These represent fragments that are smaller than the 1/4-inch mesh but larger than the fine mesh used to sieve the bulk matrix. Matrix was recovered from all levels, but only a few have been picked to extract bone and other debris.

Ambient bone was recovered from the cutbank and from all excavation units except Unit 2 (Fig. 10.2); all of the bone from that unit is considered part of the hearth deposit. Most of the bone from unit N113 E98 is also considered part of the hearth deposit, although isolated bones in excavation levels well above or below the level of the hearth (92.38 m) are considered “ambient”.

The archeological literature is replete with studies showing that 1/4-inch mesh does a poor job of sampling the remains of small animals (Thomas 1969; Shaffer 1992a, 1999; Gordon 1993; Shaffer and Sanchez 1994; James 1997; Cannon 1999; Vale and

Gargett 2002; Gobalet 2005; Nagaoka 2005; Zohar and Belmaker 2005). The gist of the literature is that coarse mesh

1) reduces the quantity of bone recovered

2) biases recovery by omitting small taxa, thereby reducing species richness and evenness

3) can alter the rank order of species abundance

4) may bias element recovery by loss of small elements.

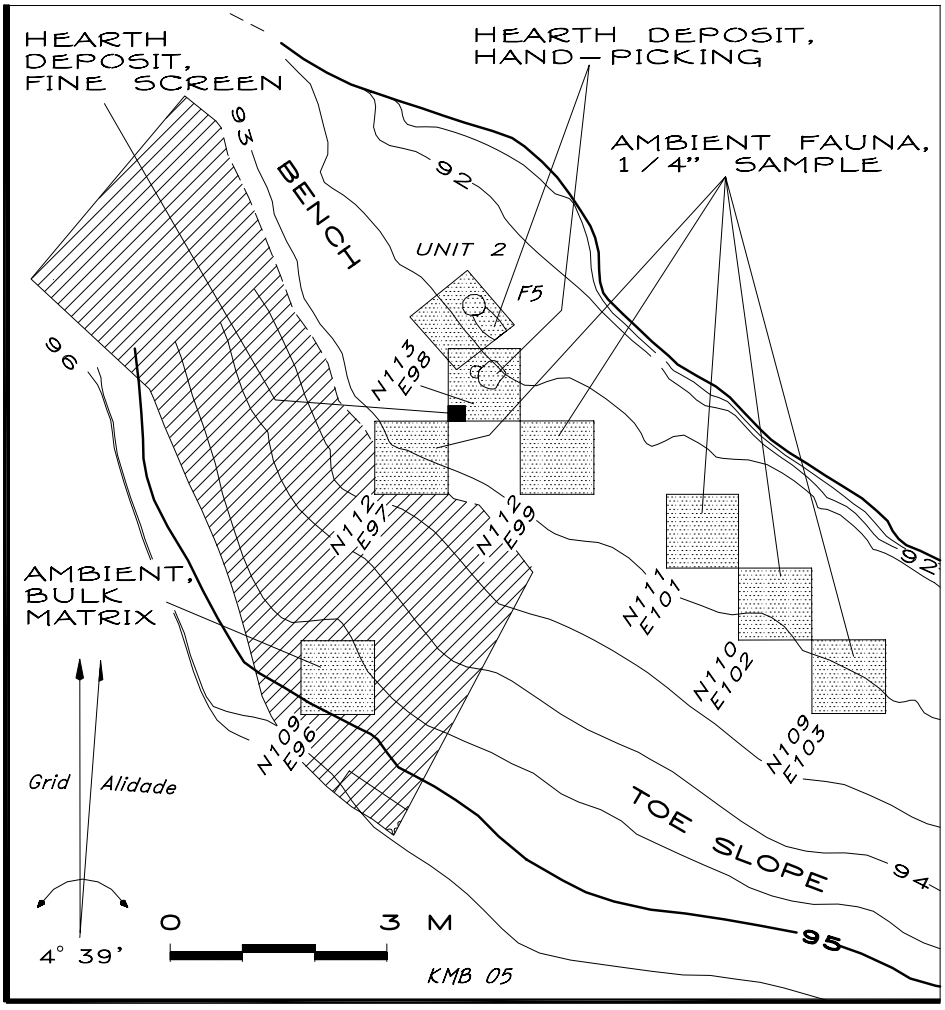


Figure 10.2. Location of Major Divisions of the Vertebrate Fauna.

The most systematic studies involve experimental sieving of disarticulated modern comparative skeletons (Shaffer 1992a, Shaffer and Sanchez 1994, Nagaoka 2005), but these studies do not duplicate the fragmented condition of archeological collections. The vertebrate remains from the bench deposits certainly bear out the first observation. Collections from the 1/4-inch screen are very sparse, and in the two units where bone was also recovered from sediment samples processed for grain-size analysis, in several cases more bone fragments were recovered from these small bulk samples (less than 2 kg) than from the rest of the level after it was passed through the 1/4-inch screen. The 1/4-inch screen, then, is an inadequate estimator of the density of ambient bone. For ambient bone from the 1/4-inch screen the average density is about 39 fragments per cubic meter (average of 115 excavation levels in six units), but many levels yielded no bone at all. The stratigraphic distribution of bone from the 1/4-inch screen is also quite erratic – there is no clearly defined preservation gradient like that seen for snails, diatoms, and freshwater sponge spicules (note that here I am using the term "bone density" to refer to the concentration of fragments in the sediments, not the hardness or compactness of the bone mineral itself).

A much better estimate of the density of ambient bone can be obtained from the bulk matrix that was passed through the 1/4-inch screen in unit N109 E96 and later fine-sieved, although only a few levels have been picked. For these eight levels, fragment counts are as follows:

93.08-93.00 m: 952
92.75-92.70 m: 386
92.70-92.65 m: 35
92.55-92.50 m: 233

92.50-92.45 m: 47
92.35-92.30 m: 359
92.15-92.10 m: 51
92.05-92.00 m: 48

The average density for these eight levels, then is about 5400 fragments per cubic meter, an estimate that is both much higher than and more realistic than that obtained from the 1/4-inch screen, but a density that is nevertheless much lower than that found in the Feature 5 hearth deposit. Figure 10.3 shows the vertical pattern of bone fragment density for the eight levels in N109 E96 (in thousands per cubic meter); the actual counts are noted beside each data point. Although there are only eight data points, there is a clear hint that ambient bone density probably declines with depth, very much like the snail shell discussed in Chapter 8. The cause, however, is unclear. The bone from stratum 2A has much the same uncorroded appearance as that from stratum 2D. There are no clear indications that bone has been removed from the deposits by chemical dissolution.

The Hearth Deposit: Excavation of a Microvertebrate Bone Bed

When the hearth, Feature 5, was originally exposed and investigated on June 29, 1979, a 1 x 1 m excavation unit (Unit 2) was laid out around it, oriented more or less parallel to the prevailing slope of the bench surface. The unit was excavated down to the baked surface of the hearth (initially estimated at 92.355 m, but later resurveyed at 92.38 m). A dense concentration of microvertebrate bone was found, mostly to the southeast of the firehardened and brightly oxidized surface (Fig. 10.4), at the same elevation as the fired surface, and in a narrow band perhaps 30 cm across at the most, extending to the edge of the excavation unit. Perhaps a few bone fragments lapped onto the fired surface

or were embedded in it. but neither the field notes nor personal recollection disclose anything about it. Most lay to the southeast in sediment that had not been heat-altered.

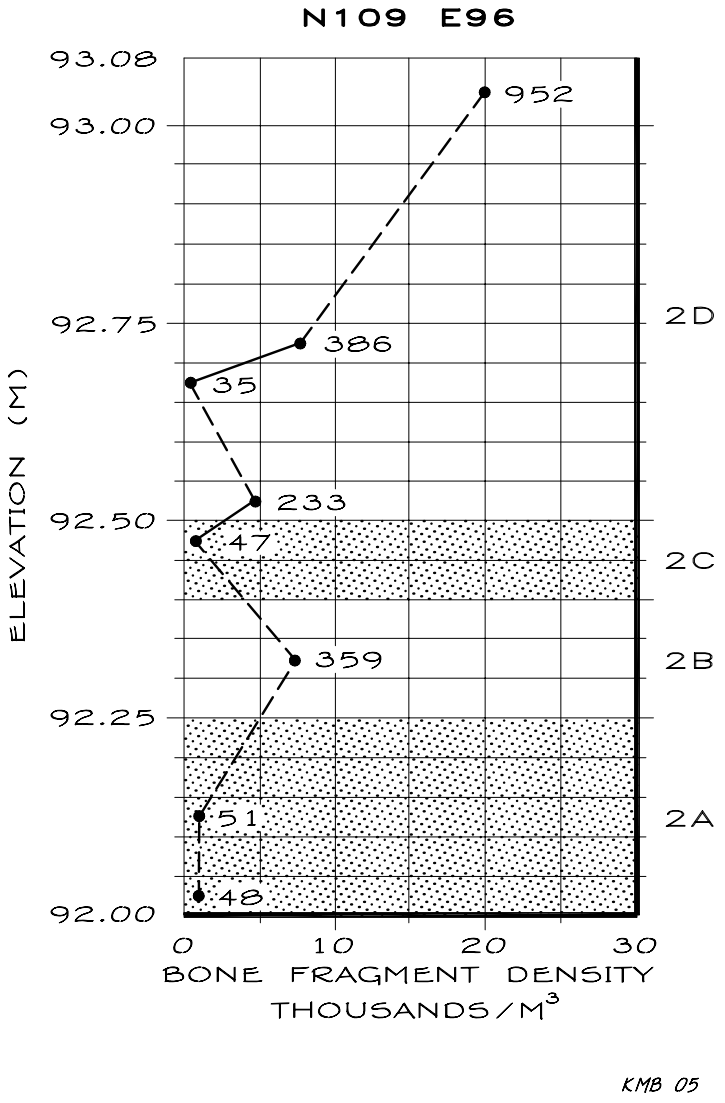


Figure 10.3. Density of Ambient Bone Fragments in N109 E96. Plot shows density of fragments (in thousands per cubic meter of fill) in the eight levels out of 21 that have been picked to extract bone and other items; from bulk matrix passing the ¼-inch screen, coarse fraction only. Although only eight levels are plotted, the curve suggests decreasing bone frequency with depth. Numbers at each density point are actual fragment count.

Animal bone from this concentration was recovered by careful exposure and hand-picking of individual elements, and very small quantities of fill were scooped into a plastic bag for later fine sieving when concentrations of very small fragments were found. All of the fill from Unit 2 was also screened in conventional fashion, but essentially nothing was found on the screen. The bone recovered from Unit 2 was later cataloged as lot B-149 (44 items) and no excavation was done below the level of the fired surface. These small animal bones were rather closely packed, but no instances of articulation were noted during excavation, which was fairly slow and careful. No additional bone was found elsewhere in Unit 2.

No additional bone from the hearth deposit was recovered until April 15, 1980, when unit N113 E98 was laid out next to Unit 2. Because this unit is on the site grid system, its northwest corner cut into the south quadrant of Unit 2 and penetrated into the abandoned floor of Unit 2. Excavation was begun in 10 cm arbitrary levels and relatively little bone was encountered in the uppermost 26-28 cm of fill, but about midway into the 92.50-92.40 m level, at 92.443 m, a dense concentration of microfauna was discovered in the north-central area of the unit (Fig. 10.4). It was immediately apparent that the same microvertebrate bone bed had been encountered, and the detection elevation was 6 cm higher in this unit than in Unit 2. At this point, the collection bag used for the 92.50-92.40 m level (lot B-105) was closed out and a new bag (lot B-106) was begun for the remainder of the level. Lot B-106 extends from about 92.44 m to the 92.40 m floor, but does not cover the entire unit because part of the unit had already been cleared down to the 92.40 m floor. Figure 10.5 shows the vertical relationship between these different lots in schematic fashion.

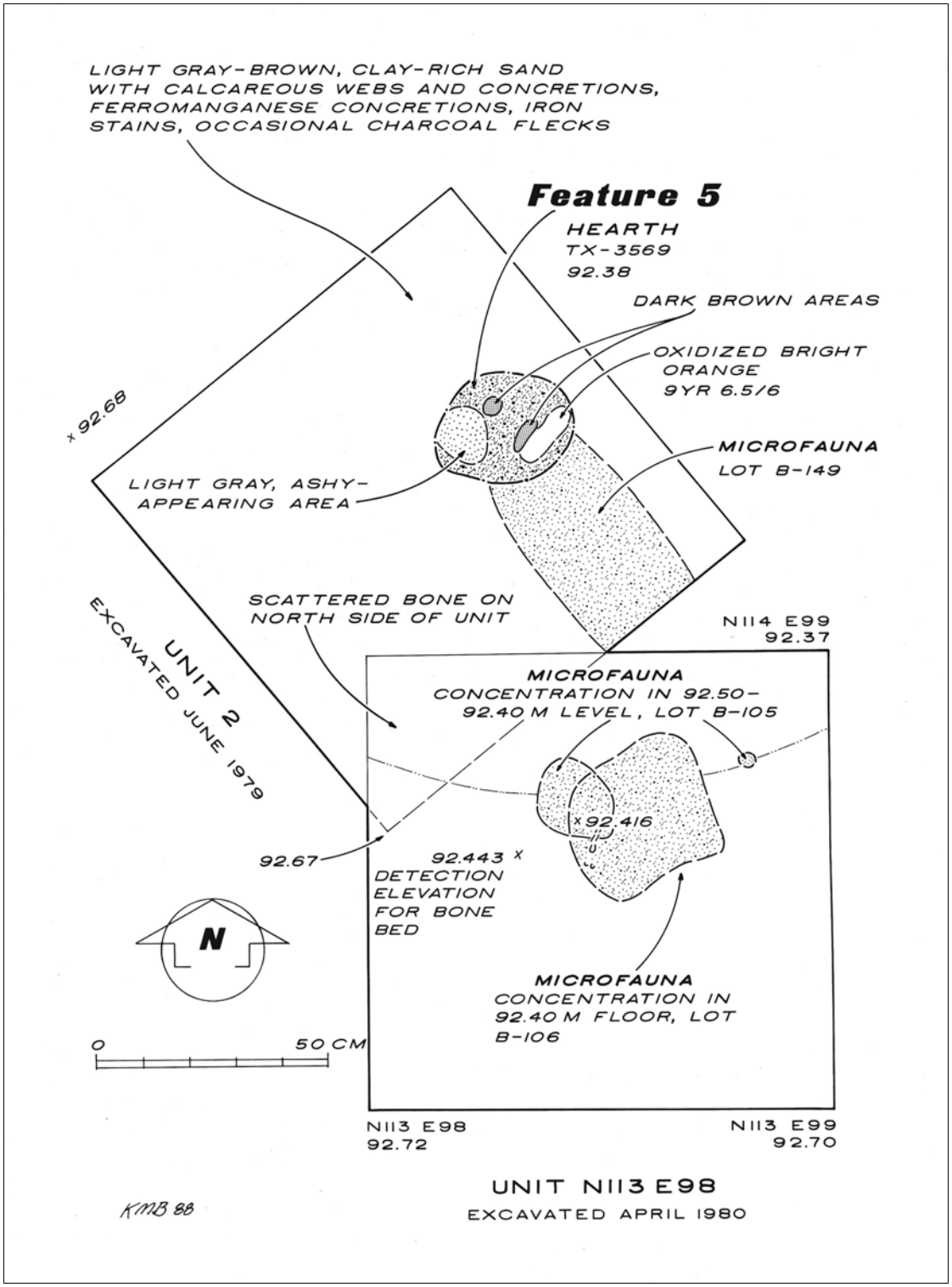


Figure 10.4. Plan of Hearth Deposit. The lower unit, N113 E98, cuts into Unit 2.

An extract from my field notes of April 15, 1980 records the circumstances of discovery:

> 92.50-92.40 …a concentration of very tiny rodent-sized bones was found near the base of this level, mainly in the north central part of the square. Detection elevation of the bone bed was 92.443 m; some bones were still showing in the 92.40 floor, but most of the bones were found above this level. The bone density drops off rapidly below 92.40 m. This concentration is definitely associated with the hearth, Feature 5, to the north. The center of the hearth is about 85 cm north of the center of the densest concentration. It is my impression that the bones are not evenly concentrated; they occur in sub-concentrations, seemingly, within the main concentration. This could perhaps indicate the concentration originated as articulated or semiarticulated units that have been disrupted by bioturbation. No definite examples of articulation were observed, but systematic exposure of the bones was not attempted. Maximum thickness of the concentration is about 4 cm; the densest concentration was about 35 cm in diameter, but bones occurred throughout the northern third of the square
>
> 92.40-92.30 Bone continues to occur in the NW quadrant of N113 E98, in the upper 5 cm, but as scattered occurrences…. (K. Brown, Berger Bluff field notes).

At about 92.42 m, the principal bone concentration was about 16 x 20 cm in diameter, centered at about N113.68 E98.45 (Fig. 10.4). In the 92.40 m floor, the principal concentration had become slightly more diffuse, shifting southeastward to center at N113.64 E9.60, enlarging to roughly 36 cm in diameter. As far as the entire bone concentration can be reconstructed from evidence in both units, it seems to have been shaped somewhat like an inverted comma, with the elongated end to the north, extending to the hearth. The maximum north-south dimension would have been perhaps 90-100 cm, and the maximum east-west width, near the south end, perhaps 30-40 cm or so. Although the bone, in many cases, appeared to lie in small clusters, there were no recognizable outlines or differently textured fills to verify the presence of coprolites or digestive pellets. No preferred orientation of the bone was noted during excavation in

either unit, although because of the contingencies of excavation, I cannot be certain that a preferred orientation would have been recognized even if present. Although a substantial area remained unexcavated in the vicinity of the bone bed at the end of the project, enough is known about its spatial distribution to suggest that it is considerably smaller and more tightly clustered than the pellet midden left by the tree-roosting great horned owl investigated by Terry (2004), where bone was found in a four-meter radius around the tree. Likewise, it is much smaller than the latrine or marking areas of most mammalian carnivores (see Andrews 1990:42).

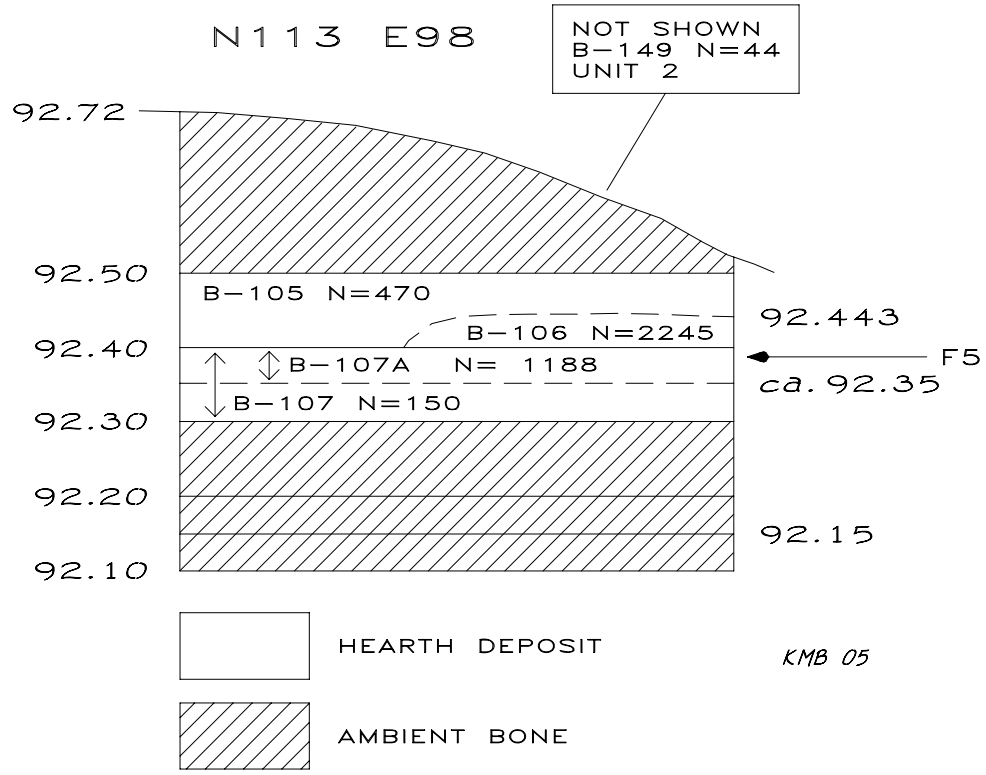


Figure 10.5. Schematic Section, Bone Lots in the Hearth Deposit. This is a schematic view, looking west, of unit N113 E98. For the actual west wall profile, see Fig. 4.36. Only the unshaded lots are considered part of the hearth deposit. Lot B-106 was collected separately when the top of the bone bed was encountered at 92.443 m. Lot B-107A was extracted from matrix collected between the 92.40 m floor and the approximate midpoint of the 92.40-92.30 m level. The arrow on the right indicates the elevation of Feature 5.

Although checking for articulated units was recognized in the field as an important problem, too little time remained to allow exposure of the microfauna *in situ*. As an alternative, apparent clusters of bone were excavated as clods of matrix to be dissected later in the lab. These were later dissolved in household vinegar and cataloged separately (note that lot B-107A has not been treated with anything and a large quantity of bone from this lot is available for potential chemical or isotope studies). Five major units in lot B-105, termed Groups 1-5, were treated this way. Group 1 was further broken down into subunits 1a through 1k. Loose fill from the 92.50-92.40 m level was designated Group 1 Residual material, and actually accounts for the greatest number of specimens. By the time lot B-106 was isolated, no apparent clusters of bone remained, so this remnant of the level was collected as loose fill and was later washed through a kitchen strainer to recover very small fragments. All of this material (except for lot B-107A, which has not been studied yet) is itemized in Appendix 6. These subclusters were not mapped when they removed because too little time remained. Excavation of the unit was terminated the next day (April 16, 1980) as the water level in the reservoir approached the unit.

This method of recovery was inconclusive for discriminating articulated units. One thing clearly demonstrated, however, is that while some clods of fill (probably the smaller ones) likely contained only a single taxon, some unmistakably contained multiple taxa. Group 3 in lot B-105, for example, contained eastern mole, frog or toad, smallmouth salamander, fish, bird, and perhaps one to three sizes of unidentified small mammals (grasshopper mouse-sized, pocket mouse-sized, and woodrat-sized). In other words, perhaps as many as eight or more different kinds of animals, depending on the actual identity of some of the small fragments that could not be identified. In this case,

each taxon seems to be represented by only one or two elements. The greatest number of elements seems to occur in Group 1g, which had 15 salamander vertebrae, possibly all from the same individual. One or two elements per taxon, however, is more typical for lot B-105 as a whole. It seems clear that the subclusters of bone recognized in the excavation floor were not partial skeletons of small animals, but instead were clusters of individual elements pooled, in some cases, from several different kinds of animals.

This is exactly what might be expected if the small clusters of bone actually represent fecal remains, or decomposed coprolites in a latrine area left by a predator with a broad-spectrum diet. Some clusters, probably the smaller ones, appear monotypic and may be the remains of a single animal. Group 1b (a hispid pocket mouse), 1f (a gopher), 1 i (an unidentified rodent), 1k (a possible small bird), Group 2 (possibly a single pocket mouse or kangaroo rat), Group 4 (a woodrat), and Group 5 (medium-sized fish) might be examples, but in these cases skeletal representation is very incomplete – only a few elements are present. The reader may wish to scan Appendix 6 to get some impression of the composition of these lots.

Because very little bone was visible when the 92.40 m floor was reached, excavation of the 92.40-92.30 m level (lot B-107) was begun without any anticipation of the need for subdivision. However, some bone began to appear once excavation got underway, so a sample of matrix from approximately the upper 5 cm of this level was bagged separately as lot B-107A. Lot B-107A ultimately yielded 1186 fragments (these have been counted but not yet identified), or about half the quantity included in lot B-106.

To summarize, five lots of bone (B-149, B-105, B-106, B-107, and B-107A) from Unit 2 and N113 E98 comprise the hearth deposit. Technically, these extend from 92.50 to 92.30 m, but it was clear during excavation that the greatest quantity of bone was tightly concentrated in a zone not much thicker than 4 cm, from 92.44 m to 92.40 m or slightly below. My interpretation of this bone bed is that it represents a single relatively short-term (perhaps less than a year?) depositional event on a single surface. The bone deposit has experienced slight postdepositional bioturbation that has dispersed part of it vertically over a span of no more than a few centimeters, and horizontally no more than a few decimeters. The depositional surface may have sloped upward slightly to the southeast, since the detection elevation here was slightly higher than next to the hearth. No ash, charcoal, or fired clay was found mixed with the bone in N113 E98 to suggest the bone had been raked out of the hearth.

Estimating the density of the bone deposit is difficult because the bone was not uniformly distributed within the arbitrary levels used. If we assume the densest part occurred between 92.44 and 92.35 m, then 3444 fragments were recovered from this space, giving a calculated density of more than 38,266 fragments per cubic meter of fill. This is about seven times as great as the ambient bone density established by fine sieving of bulk matrix from N109 E96 (see earlier discussion, above), a method that ought to be comparable to that used here. Essentially all the bone in the hearth deposit was recovered either by fine sieving of clods or small quantities of loose matrix scraped directly off the excavation floor, or by careful hand-picking of *in situ* fragments exposed during excavation. Little or no bone was recovered on the 1/4-inch screen from these levels. It is clear that this was an effective recovery method for microvertebrate remains.

It is also clear that there are significant differences in density and composition between the ambient and hearth-related vertebrate remains, even when comparable fine sieve recovery methods are used. When unidentified bone fragments are omitted from consideration, the hearth deposit has large numbers of bone fragments from salamander (perhaps all *Ambystoma texanum*), followed in ranked abundance by eastern mole, unidentified fish, various snakes (especially Colubridae), frogs or toads (perhaps mostly Rio Grande leopard frog and American toad), pocket gophers, unidentified small birds, pocket mice, woodrats, lizards, and several other less abundant taxa (Fig. 10.6; Fig. 10.7 includes unidentified categories). The ambient bone has material from rabbits (probably mostly cottontails, but perhaps including some jackrabbits), followed in ranked order by pocket gophers, turtles (cooters or sliders, mud or musk turtles), fish (including gar), salamanders, frogs or toads, small birds, snakes (including water snake), raccoon, cotton rats, kangaroo rats, pocket mice, shrews, and several other taxa; eastern moles are infrequent (Fig. 10.8).

The most salient compositional differences are the appearance of turtle, raccoon, and cotton rat among the ambient fauna, the diminished importance of salamanders, and the reversed abundance of rabbits and moles. Rabbits are abundant and moles scarce in the ambient fauna, but the reverse is true for the hearth deposit. Some of these differences are probably the result of differing recovery techniques. If all of the matrix residue samples from N109 E96 could be picked and the bone identified, some of the apparent differences between ambient and hearth-related bone might be diminished.

Table 10.13 lists the relevant lot numbers for the different categories of bone.

Table 10.13. Lot Numbers for Animal Bone.

Ambient Bone, Identified and Inventoried		
B-104	B-43	B-125
B-108	B-44	B-126
B-109	B-45	B-128
B-110	B-46	B-129
B-150	B-50	B-130
B-1	B-51	B-131
B-2	B-52	B-133
B-3	B-54	B-134
B-4	B-57	B-135
B-5	B-59	B-136
B-6	B-61	B-137
B-7	B-62	B-139
B-8	B-62A	B-140
B-9	B-63	B-141
B-11	B-69	B-141A
B-16	B-72	B-142
B-17	B-73	B-143
B-18	B-76	B-144
B-19	B-86	B-146
B-28	B-88A	B-147
B-29	B-89	B-148
B-31	B-91	B-154
B-32	B-92	B-156
B-33	B-98	B-157 *
B-34	B-101	B-158 *
B-35	B-111	B-159 *
B-36	B-116	
B-40	B-123	
Hearth Deposit, Identified and Inventoried		
B-105	B-107	
B-106	B-149	
Hearth Deposit, Not Yet Identified or Inventoried		
B-107A		

* Note: at present, these are the only N109 E96 bulk matrix lots with numbers assigned.

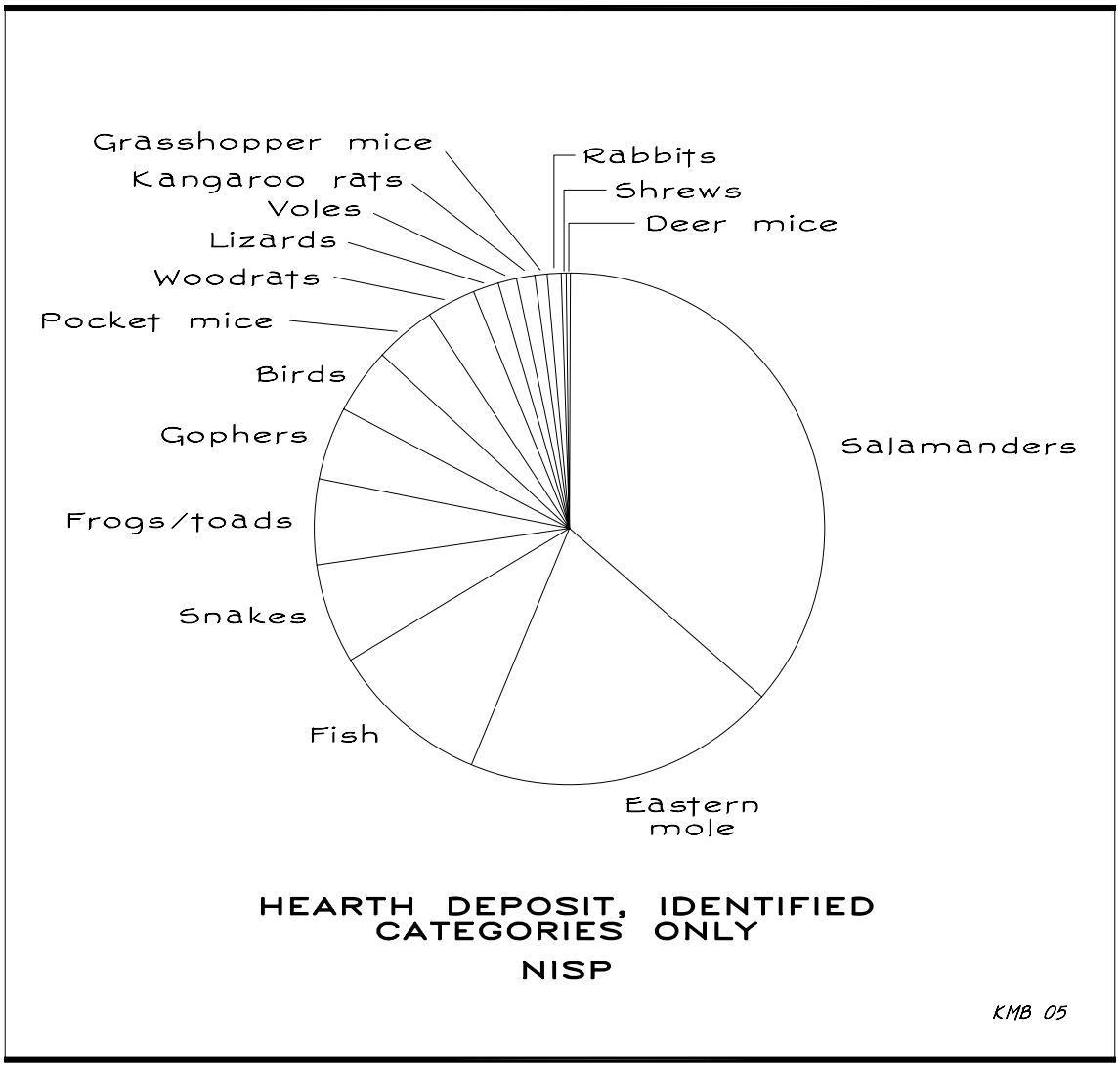


Figure 10.6. Hearth Deposit, Taxonomic Composition by Number of Specimens. Relative proportions of major vertebrate categories are ranked by NISP. Unidentified categories (unidentified vertebrate, unidentified mammal, small mammal, mesomammal, etc.) are omitted, so only 448 out of the 2909 fragments studied are actually graphed here. Categories vary in taxonomic breadth from class (Class Aves, Class Osteichthyes, for taxa that cannot be identified any more precisely) to species (*Onychomys leucogaster*, grasshopper mice). Note that the most abundant taxa are chiefly riparian ones.

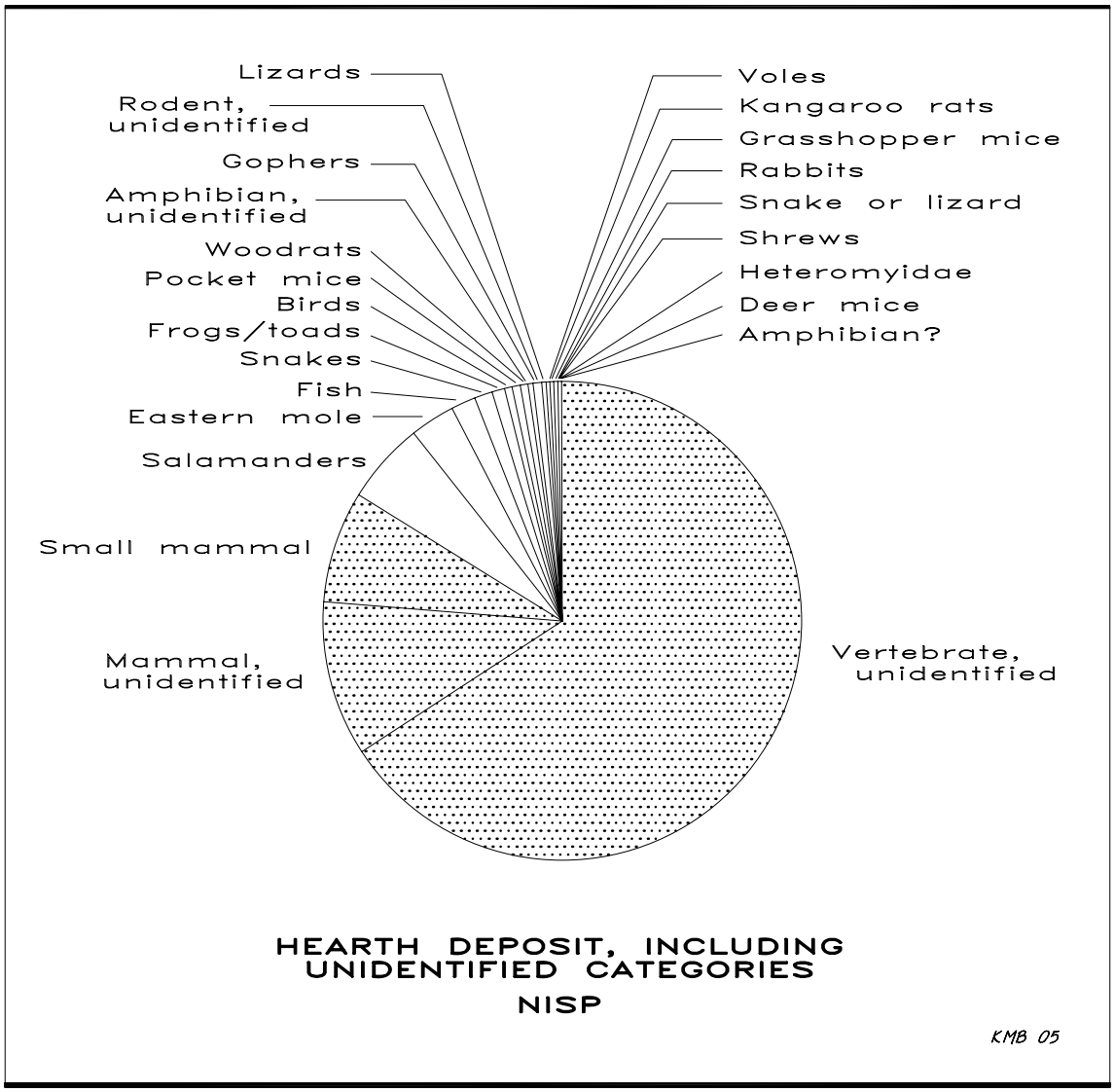


Figure 10.7. Hearth Deposit, Taxonomic Composition With Unidentified Categories. Relative proportions of major vertebrate categories are ranked by NISP, with various categories of unidentified fragments (shaded area) included. About 83% of the fragments fall into these unidentified categories.

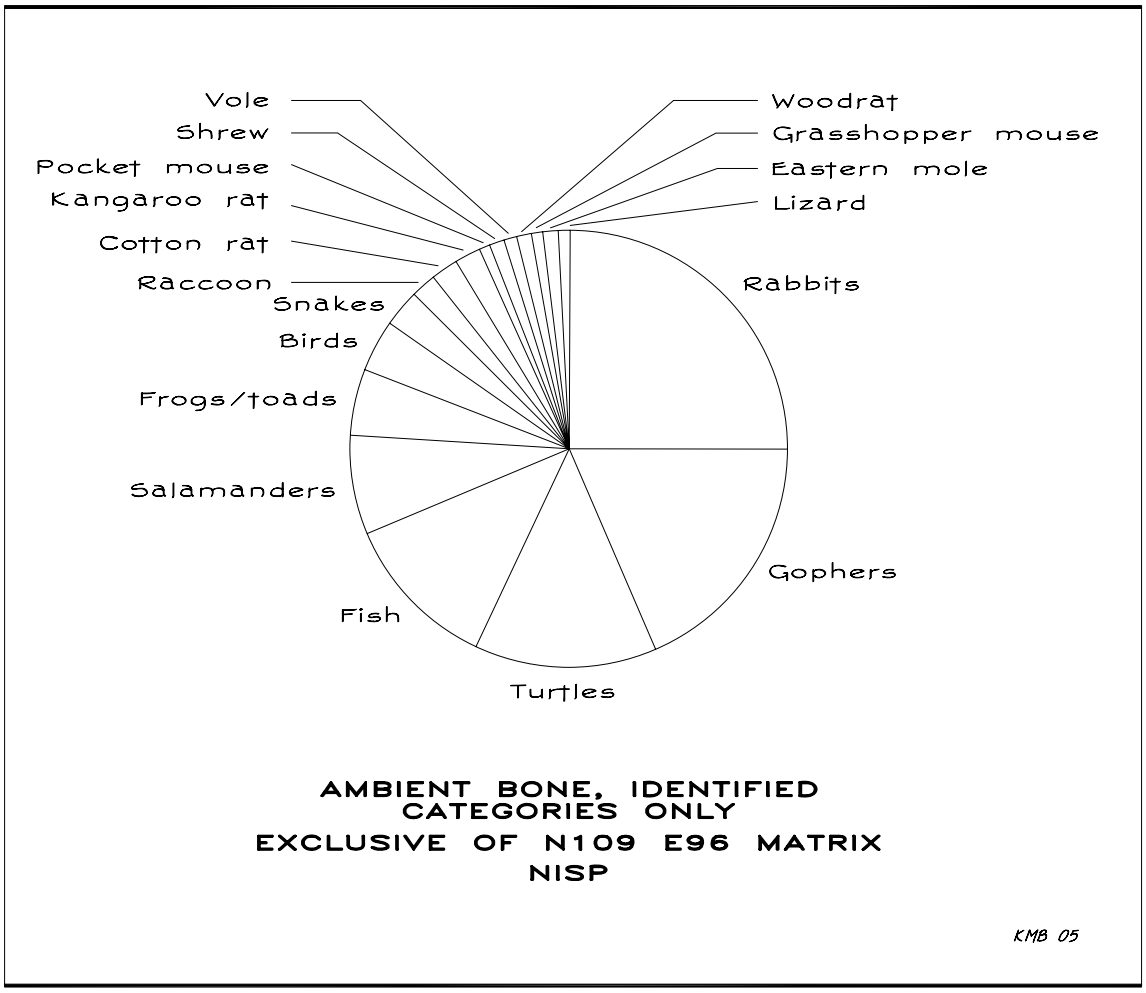


Figure 10.8. Ambient Bone: Taxonomic Composition by Number of Specimens. Relative proportions of major vertebrate categories are ranked by NISP. Unidentified categories (unidentified vertebrate, unidentified mammal, small mammal, mesomammal, etc.) are omitted, so only 103 out of the 587 fragments studied are actually graphed here. Categories vary in taxonomic breadth from class (Class Aves, Class Osteichthyes, for taxa that cannot be identified any more precisely) to species (*Procyon lotor*, or raccoon). Note that both riparian and upland taxa are represented.

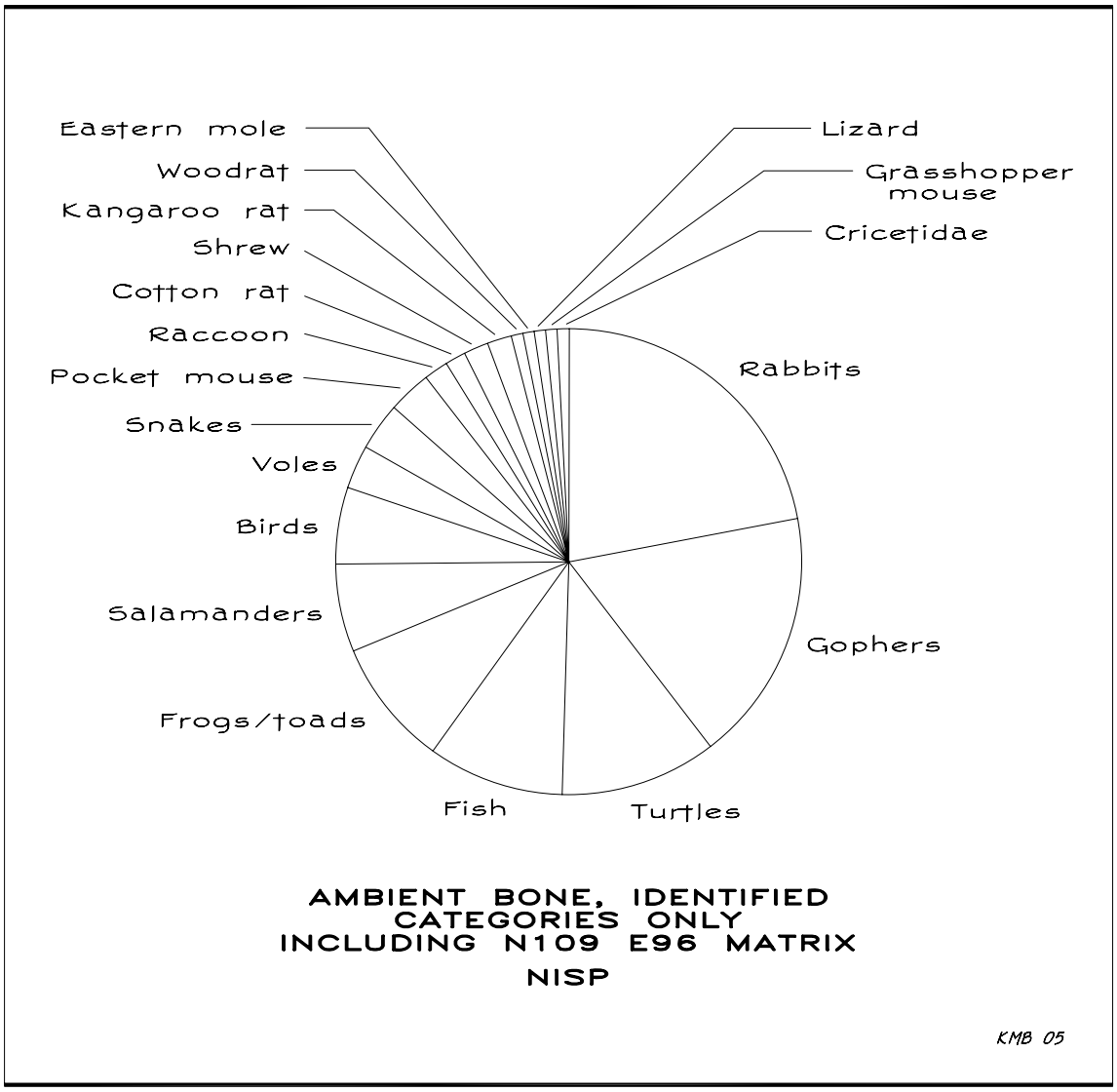


Figure 10.9. Ambient Bone: Taxonomic Composition by Number of Specimens. Relative proportions of major vertebrate categories are ranked by NISP. This graph is similar to the previous figure, but some identified bone from matrix passing the ¼-inch screen in unit N109 E96 is added to the tallies (Note: for matrix samples, only three levels are included, and not all the bone from the levels is tallied). Unidentified categories (unidentified vertebrate, unidentified mammal, small mammal, mesomammal, etc.) are omitted, so only 127 fragments studied are actually graphed here. Adding these specimens from fine-screen recovery changes the relative positions of some of the less common categories and adds one general category, a cricetid mouse.

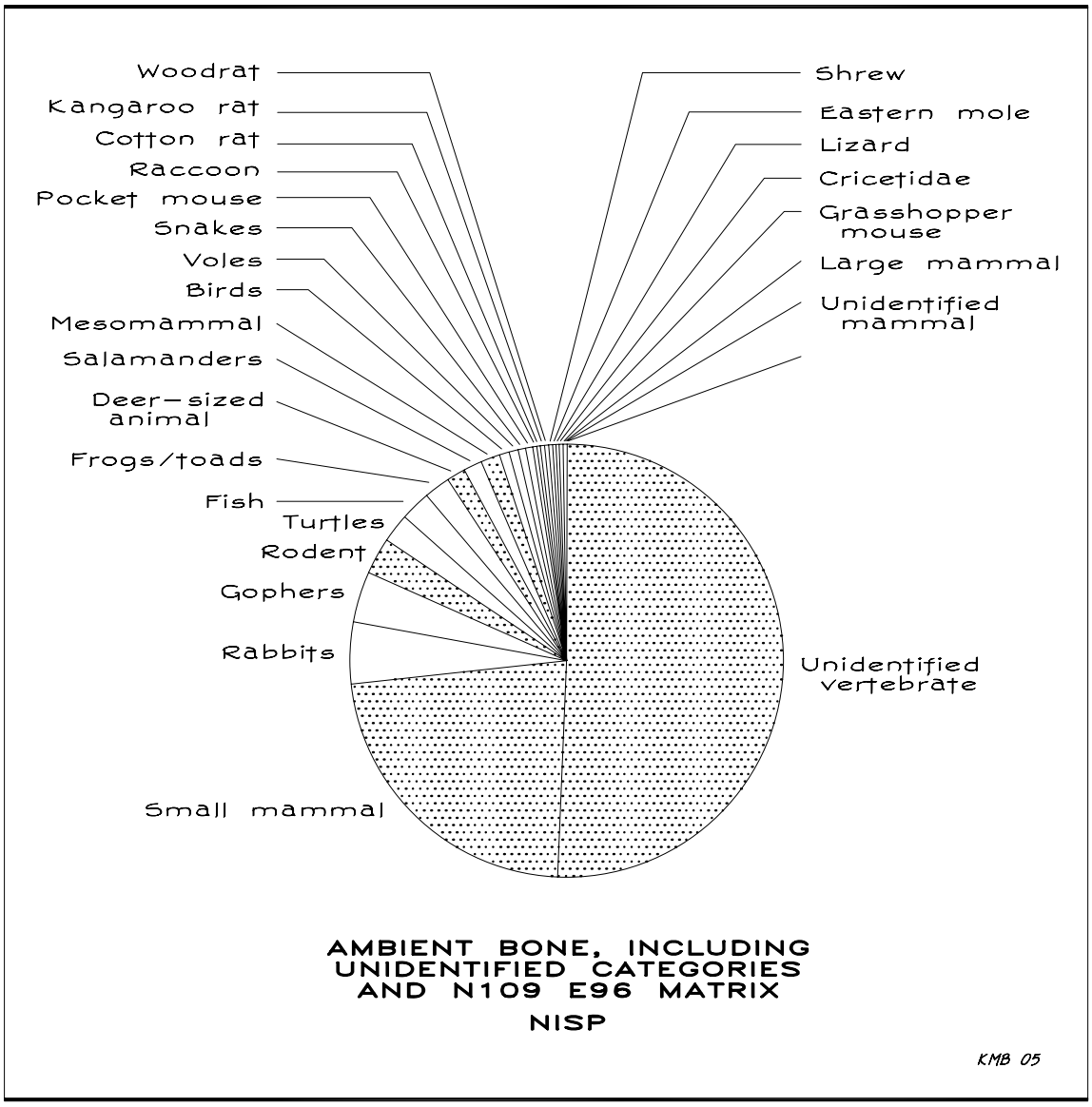


Figure 10.10. Ambient Bone: Taxonomic Composition by Number of Specimens. Relative proportions of major vertebrate categories are ranked by NISP. Unidentified categories (unidentified vertebrate, small mammal, mesomammal, etc.) are shaded and represent the two most abundant categories. Some identified bone from matrix passing the ¼-inch screen in unit N109 E96 is added to the tallies (Note: for matrix samples, only three levels are included, and not all the bone from the levels is tallied). Categories vary in taxonomic breadth from class (Class Aves, Class Osteichthyes, for taxa that cannot be identified any more precisely) to species (*Procyon lotor*, or raccoon).

CONDITION OF THE BONE

Taphonomy embraces a chain of several different processes: bone breakage, mastication, or dismemberment by predators; postmortem dispersal and breakage of skeletons by scavengers or flooding; bone loss; above-ground weathering; further diagenesis after burial, and breakage as a result of soil expansion and contraction. Some of these are relevant to the bench deposits, while others are not.

Limited Evidence for Weathering

Behrensmeyer (1978:153) uses the term *weathering* to describe physical changes in bone both above and below ground, and Lyman (1994:354) apparently follows the same usage. I think it is useful to have a term restricted to above-ground alteration, and I prefer to use the term "weathering" only for above-ground breakdown of bone (as does Andrews 1990:10). I prefer to use the term *diagenesis* for all postmortem changes in bone, either above-ground or below ground. In my view, diagenesis of most bone starts with above-ground weathering, then continues with a different set of alteration processes after burial.

The appearance and state of preservation of the ambient and hearth-related bone is essentially the same, so both categories can be discussed together here. The most important modification is mechanical breakage. Breakage can occur 1) during predation (from mastication, dismemberment, or digestive processes), 2) during burial (from matrix expansion and contraction), or 3) during excavation by the archeologist. All three are probably evident in the bench assemblage, and I will discuss these at some length later in the chapter. There is an enormous literature on the taphonomy of small animal remains (mostly small mammals) in raptor pellets and animal scats, but nearly all this literature

deals with the early stages of bone breakage, digestion, and breakdown. Very little of it deals with the weathering processes that occur after pellet middens or latrines are created. Behrensmeyer (1978) has defined a series of six progressive weathering stages for large mammals in east Africa (the scheme is only applicable to mammals over 5 kg body weight). None of the animal bone from the bench deposits shows any appreciable correspondence to any of the weathering stages defined by Behrensmeyer, except perhaps for very rare, minor longitudinal cracking. Otherwise, the bone appears unweathered and does not resemble bone that has been long exposed on the ground surface. The deep cracking, flaking, and exposed fibrous texture documented by Behrensmeyer are absent here. According to Andrews and Armour-Chelu (1998:438), weathering in wet temperate climates is much slower.

Studies of weathering effects on small mammal bone by Andrews (1990:10-16), on amphibian bone by Pinto and Andrews (1999:422-424), a study of bone dispersal by Terry (2004), studies of bird bone weathering (Bocheński and Tomek 1997) and bioerosion (Davis 1997) and very brief comments by Bickart (1984:532) are much more relevant. Andrews exposed barn owl pellets to weathering in a wet temperate climate, and found no weathering of the enclosed bone after two years. Additional weathering of exposed bone produced minimal changes. His results for small mammal bone (documented by SEM photography) can be summarized as follows (from Andrews 1990:Table 1.3):

0-2 years: no modification
1-5 years: slight splitting of bone, chipping of teeth and splitting of dentine
3-5+ years: more extensive splitting, but little flaking of bone; chipping and splitting of teeth leading to loss of parts of crown
4-5+ years: deep splitting and some loss of deep segments between splits; extensive splitting of teeth

Bone from the bench deposits corresponds either to Andrews's stage 1 (unaltered) or incipient stage 2; occasional splitting of long bones is seen but the chipping of occlusal surfaces of teeth (Andrews 1990:Figs. 1.4, D-G; 1.5, B-D; 1.6, A-E) seems to be absent (compare with occlusal surface photos presented later in this chapter), and much of the longitudinal splitting of long bone in the bench deposits is due to interior carbonate growth after burial, not to weathering.

Pinto and Andrews left frog skeletons exposed to weathering for 18 months, finding microscopic longitudinal splitting and slight surface erosion on bones placed with a southern exposure (Pinto and Andrews 1999:Fig. 6A), but no splitting on bone with a northern exposure. This type of splitting is not visible on amphibian bone from the bench examined at magnifications up to 70X with a conventional binocular microscope.

Why Is Evidence for Weathering Limited?

It may seem paradoxical that the animal bone from the bench deposits shows few indications of weathering, given the evidence (presented in Chapter 4) that depositional rates of fine-grained Coleto Creek floodplain sediments were not particularly high. With relatively slow depositional rates, extensive weathering might be expected, if the depositional microenvironment were not a factor. However, I suspect the microenvironment was in fact a controlling variable. In Chapter 4, I showed that there is limited evidence for weathering of the sediment itself, and the same can be said of the inclusions in it. The chert, for example, is unpatinated.

Thanks to studies by Trueman and others (2004) and Nielsen-Marsh (2000), the physical processes of large mammal bone weathering are well understood. A bone resting on the ground surface draws up pore water from the soil and evaporates it to the atmosphere on exposed surfaces (a wicking process); organic material (and nitrogen) is lost, bone crystal size increases, authigenic minerals (calcite, barite, and others) accumulate, and macroscopic splitting, cracking and flaking occur. Macroporosity increases, while microporosity decreases. Degradation of collagen is driven by temperature fluctuations and the presence of UV light (Trueman *et al*. 2004:736). Major physical changes occur in surface-resting bone within about two to five years after deposition. However, the conditions in Kenya under which Trueman and others carried out their study are probably quite different from those found on the late Pleistocene-early Holocene Coleto Creek valley floor, where temperatures were lower and less variable, moisture levels much higher and less variable, but most critically, heavy tree cover was probably present. During the growing season, extensive deciduous tree canopy not only shields the site from UV radiation, it acts as thermal insulation and creates a layer of leaf litter that in itself acts as a shielding microenvironment. In Chapter 8, I showed how this kind of microenvironment is critical to the survival of moisture-dependent and saprophilous snail species. For large mammal bone, Behrensmeyer (1978:159) suggests that weathering is slower in more heavily vegetated habitats. Experiments by Brain (1981:115-116 and Fig. 120) show that bleaching, cracking and protein loss are retarded by shade. According to Brain, in shaded situations, fat may be retained in bones for decades. I suspect that the Coleto Creek floodplain supported a heavy deciduous tree canopy during the late Pleistocene and early Holocene, significantly reducing UV light levels and fluctuations in moisture and temperature, and this canopy was a critical factor in sustaining snail and amphibian populations, as well as retarding bone weathering.

Color and Texture Groups

Regardless of whether ambient or hearth-related bone is considered, there is some variation in the color and surface texture of the fragments. Scattered throughout the deposits are occasional fragments that have obviously been discolored or otherwise altered by exposure to fire. These are not abundant, but they are present in both ambient and hearth-related bone. Figure 10.11 is a macrophoto of a small unidentifiable fragment selected to show the effects of pronounced calcining.

The largest group of fragments consists of semi-glossy, reddish-brown, orange, or brown fragments. These are well-preserved, appear hard, perhaps proteinaceous, and when broken may exhibit spiral-like fractures. The source of the rubification is unknown; it does not appear to be fire-reddening. It may be preferential uptake of iron from groundwater, but if so, is remarkably uniform. The color affects the whole bone, not just the surface. Figure 10.12 shows two very small unidentified fragments selected from the N109 E96 bulk matrix sample to illustrate this color-texture class. The kind of vertebrate and the element are unknown. The source of the edge rounding on the upper example is unknown; it could be gastric digestion or groundwater diagenesis, but is not typical of the most of the bone from the bench. Notice the hard, glossy texture and absence of surface pitting or etching, splitting, or flaking. This group appears unweathered and little altered except for fragmentation (either perimorten or in the ground) and rubification.

The second, slightly less abundant group consists of beige, earthy or matte-textured fragments that appear more porous and softer, and perhaps less proteinaceous (?). It is not clear whether this group has experienced slight weathering or whether there

might be some other cause for the different appearance. Because these fragments are more porous, they are much more likely to have black surface manganese stains and yellow uranium oxide stains. Figure 10.13 shows a small unidentified fragment from the same provenience as the previous examples. Note the nonglossy, slightly pitted appearance and the irregular broken edge.

Figure 10.11. Calcined Bone Fragment. Macrophoto of a small unidentified ambient bone fragment, showing crazing and white to gray colors characteristic of calcining. This specimen was found in the vicinity of Feature 7 (Fig. 4.49) and could be associated with it. N109 E96 (92.35-92.30 m), bulk matrix, coarse fraction.

Why, then, are there two different color-texture groups in the same deposits? One hypothesis might be that these represent both unweathered and slightly weathered groups

that entered the site through somewhat different taphonomic pathways. This seems unlikely, however, because both groups are present in the same samples, and in particular both groups are present in the hearth deposit, a bone bed which there is good reason to suspect accumulated as a relatively short-term single event. Another possibility is that the color-texture groups represent slightly different responses to diagenesis by different taxa or different elements. Some of the bone comes from animals spending part or all of their lives in water (fish, frogs, salamanders), and these, like the birds, probably have less dense bone than terrestrial, cursorial mammals. Likewise, some elements (scapulae, for example) may have less dense bone than load-bearing long bones, or teeth. Weathering responses of different elements from the same carcass are known to vary according to exposure history (Lyman and Fox 1989:300). This problem could be attacked by scoring the fragments individually for taxon, element, color, and texture, but that level of detail is beyond the scope of the present study. The fragments is Appendix 6 have been scored for taxon and element, and some of the fragments from the N109 E96 matrix have been scored for color, but the complete set of characters has not been recorded for any sample.

In order to investigate the size distribution and color patterning of the ambient bone, fragments from three excavation levels (92.05-92.00 m, 92.15-10 m, and 92.35-92.30 m) in the lower part of unit N109 E96 were recorded. This sample consists of a total of 414 bone fragments (not yet identified or sorted by species) picked from the coarse fraction residue derived from the bulk matrix passing the 1/4-inch screen in this unit.

The maximum dimension of each bone fragment was recorded to the nearest 0.1 mm with dial calipers, and a Munsell color was recorded except where the bone fragment

was too small or the surface was not clearly visible; color could be recorded for 275 fragments. Munsell notations were entered in a spreadsheet and a cluster analysis was done. The cluster analysis (not illustrated here because the dendrograph is too complex for legibility) revealed three principal groups:

Group 1: a large group (56%) of reddish-brown, semi-glossy fragments averaging about 3.82 YR 4.58/4.20

Group 2: a slightly smaller number (41%) of beige, matte-textured fragments averaging about 7.28 YR 6.16/4.10

Group 3: a very small number (3%) of gray or white calcined bone fragments averaging about 3.33 YR 4.13/0.33

Manganese and Uranium Oxide Staining

Black manganese dioxide surface coatings are fairly common on many of the bone fragments from the bench deposits. In most cases, these are small irregular patches, but one or two very small fragments entirely coated in manganese stains have been seen. These can be distinguished from charred bone by careful examination under magnification. Stained bones are probably more common among the more porous, beige, matte-textured color group.

Manganese-stained bones are perhaps most often reported from wet cave deposits in limestone terrain (Shahack-Gross 1997; López-González, Grandal-d'Anglade and Vidal-Romaní 2006) where the stains are formed by manganese-oxidizing bacteria in damp but oxygenated, contexts with circumneutral pH. Occasionally, examples are reported from open sites (Bloom 1986:236).

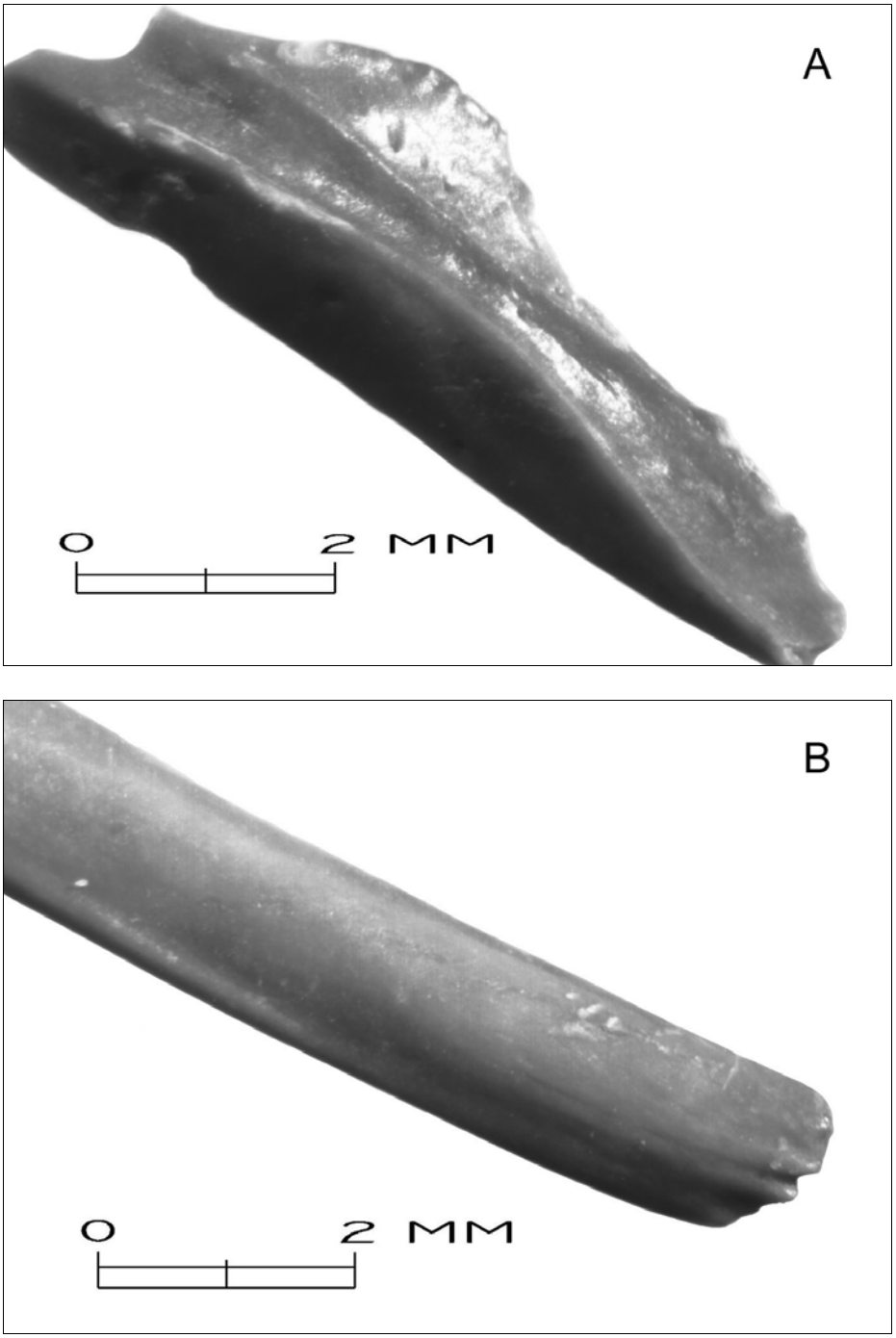


Figure 10.12. Examples of Semiglossy Texture. Macrophotos of unidentified fragments, both red-brown and semiglossy, from N109 E96 (92.35-92.30 m), bulk matrix, coarse fraction. Edge rounding on "A" is not typical, and the cause is unknown. Note absence of pitting, splitting, or root etching.

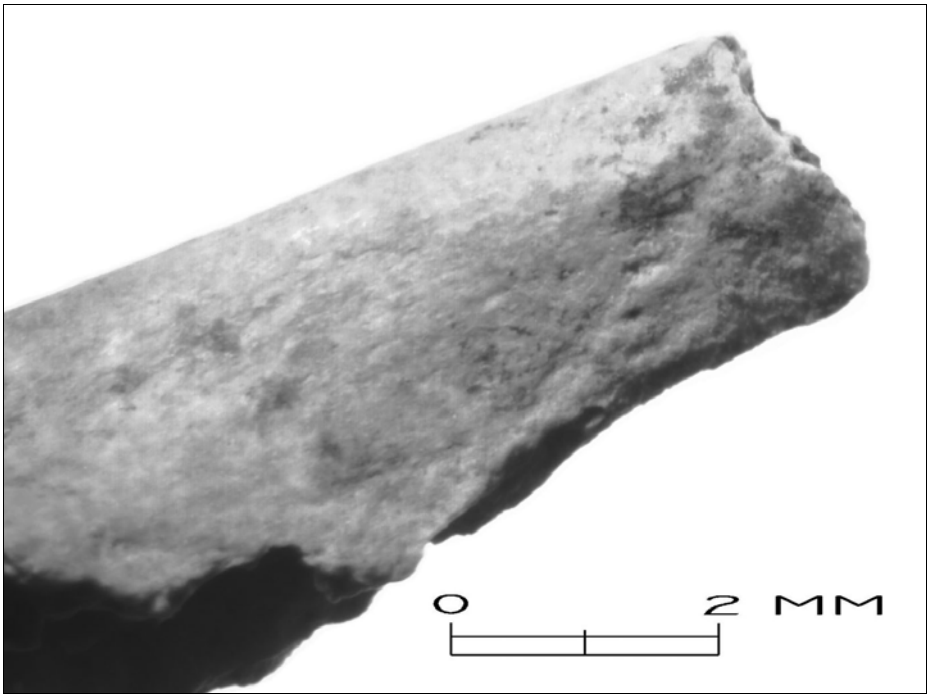


Figure 10.13. Example of Matte Texture. This small unidentified fragment comes from the same lot as the fragments in the previous figure, but is beige with a matte texture and appears slightly weathered in comparison. N109 E96 (92.35-92.30 m), bulk matrix, coarse fraction.

Less common than manganese-stained bones are examples with a distinct yellow cast that is suspected to be uranium oxide staining (see discussion in Chapter 4). These, too, are probably found mainly among the beige, matte-textured group. According to Millard and Hedges (1995), uranium content is higher in sites that are annually flooded or that receive vadose water than waterlogged sites. Likewise, uranium content is higher in sites with carbonate deposits than in peat.

Carbonate Deposits

The animal bone from the bench deposits is unmineralized – that is, there is no evidence of replacement of bone constituents by minerals in groundwater – but many of the bones are heavily lime-encrusted. The crusts are simply patches of the enclosing sediment (silt and clay particles, quartz sand) cemented in calcium carbonate that appear identical in color, texture and hardness to the calcrete pans and rhizoconcretions discussed in Chapter 4. Most of these encrustations are so hard that they cannot be removed without destroying the bone. In some cases these have formed on the exterior surfaces of intact bones. In cases where bone breakage occurred before or during burial, breakage has provided an entry route for groundwater to invade the interior of the bone and deposit carbonate inside, in many cases splitting and forcing the bone apart as a result of continued carbonate growth (Fig. 10.14). In the collection are a number of "exploded" rodent mandibles that have been slowly forced apart by calcareous growths, retaining the teeth and mandible fragments in more or less correct anatomical position. In cases where some teeth have fallen out of their sockets before or after burial, the vacant alveoli have probably provided entry routes for carbonate.

Rodent Gnawing and Root Etching

No examples of rodent or carnivore gnawing have been seen. Nearly all the bone is below the size range in which such damage is normally seen, in any case. Likewise, no examples of root etching were seen (see Fisher 1995:Fig. 12 for an example). Surface channels (see below) are present, but seem too small and too abrasive in nature to represent root etching.

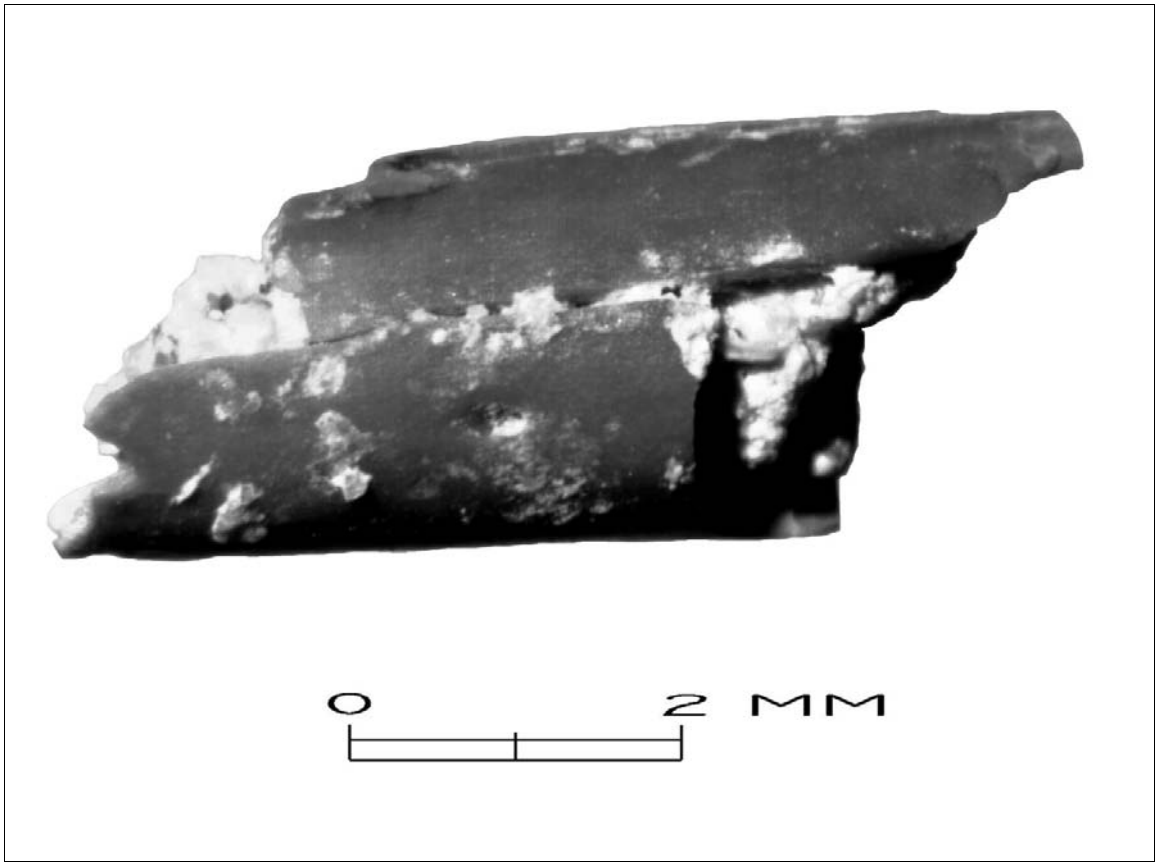


Figure 10.14. Carbonate Growth Forces Longitudinal Splitting. The original break on this very small unidentified tubular bone fragment allowed carbonate growth to occur in the interior, resulting in longitudinal splitting. The carbonate here is white and powdery, unlike the hard gray carbonate most commonly seen. N109 E96 (92.35-92.30 m), bulk matrix, coarse fraction.

Fungal Bioerosion, Channeling and Pitting

Fungal degradation is an important part of bone diagenesis. The process starts with above-ground weathering, and since fungi are aerobic, it can continue after burial as long as the burial medium is moist and oxygenated (bacteria may possibly be implicated,

as well). Fungal erosion results in tunnels and channels, termed "Hackett tunnels," about 0.25 mm in width (Davis 1997:397). Presumably, fungal hyphae generate either acid hydrolysis or enzymes (collagenases) that create localized dissolution of the bone. Nicholson (1996:518) reports experimentally produced channels are about 0.5-2.0 mm long and 0.03-0.10 mm wide, and she also reports pits about 0.02-0.05 mm in diameter. Features this size are large enough to be seen with conventional light microscopy. For illustrations, see Nicholson (1996:Figs. 3, 4) and Davis (1997:Fig. 13). Several authors also report much smaller fungal tunnels and channels about 2-10 μm in width (Davis 1997:389-390) that would not be readily observable with conventional binocular microscopy. Trueman and Martill (2002:376) report a variety of tunnel-like ("Wedl tunnels") and hole-like features ranging in size from about 5 μm up to 15 or even 30 μm in diameter in very old fossil bone. Features this size should be detectable by thin sectioning or scanning electron microscopy, but not by ordinary binocular microscopy.

Detecting fungal bioerosion may be important because it removes collagen, affecting the suitability of the bone for radiocarbon assay, and because its presence or absence may clarify the mode of death. Butchery, defleshing or cooking may remove bacteria in the gut contents and impede bacterial degradation, as well as removing tissue that might serve as a postmortem host for fungi (Trueman and Martill 2002:380-381). To check for evidence of large-scale bioerosion features, small samples of ambient and hearth deposit bone fragments were examined under a binocular microscope at 70X (SEM imaging or histological thin sections were considered too ambitious for the present study). At this magnification, features about 0.02 mm or greater in width ought to be recognizable. The following samples were examined: from the hearth deposit (lot B-107A), 87 bone fragments; from the ambient bone (five lots from N109 E96 bulk matrix,

see below), 150 fragments. No definite examples of fungal bioerosion were seen at this magnification, and indeed I would not expect features 30 μm or less in diameter to be visible in any case, so this effort was inconclusive. However, other kinds of surface modifications were visible at 70X.

A small percentage of the fragments examined at 70X had surface channels or scars. Most of these appear to be abrasive rather than chemical in nature. These may be straight or meandering, are often transverse to the long axis of the bone, and are usually about 0.2 mm wide. Most are not very deep, though some are deep enough to expose the medullary cavity. One of the more extreme and deeply channeled examples is shown in Fig. 10.15. This one, which resembles a termite-riddled stick, is partially obscured by white powdery carbonate that has infilled many of the features. In five samples selected from the N109 E96 bulk matrix samples, the following showed channeling:

92.05-92.00 m: 5 out of 40 channeled
92.15-92.10 m: 0 out of 3 channeled
92.15-92.10 m, NE half: 0 out of 13 channeled
92.35-92.30 m: 1 out of 21 channeled
92.55-92.50m: 8 out of 76 channeled

Nearly all the best-developed examples of channeling were seen on short sections of long bone shafts, probably from small rodents or insectivores. For some reason, other kinds of fragments (vertebrae, maxillary or cranial fragments) were mostly unaffected.

Much more common than channels are small, shallow pits usually about 0.4 mm across but ranging from 0.1 to as much as 1.2 mm or more in diameter. They are so diverse in concentration and size that I did not tally their frequency. In some cases these

are clustered or coalesced to form larger cratered or "gnawed" appearing fields, often near the end of a bone fragment. The more extreme examples resemble termite-infested wood, and indeed it may be in some cases that both channeling and pitting are due to some kind of insect predation (carrion beetles?; *cf*. Korth 1979:260), either above ground, in leaf litter, or after burial. Both pits and channels seem to be uncommon on amphibian or fish bone, perhaps because of differences in bone hardness. They are probably too small to represent rodent gnawing, and are easily overlooked without magnification.

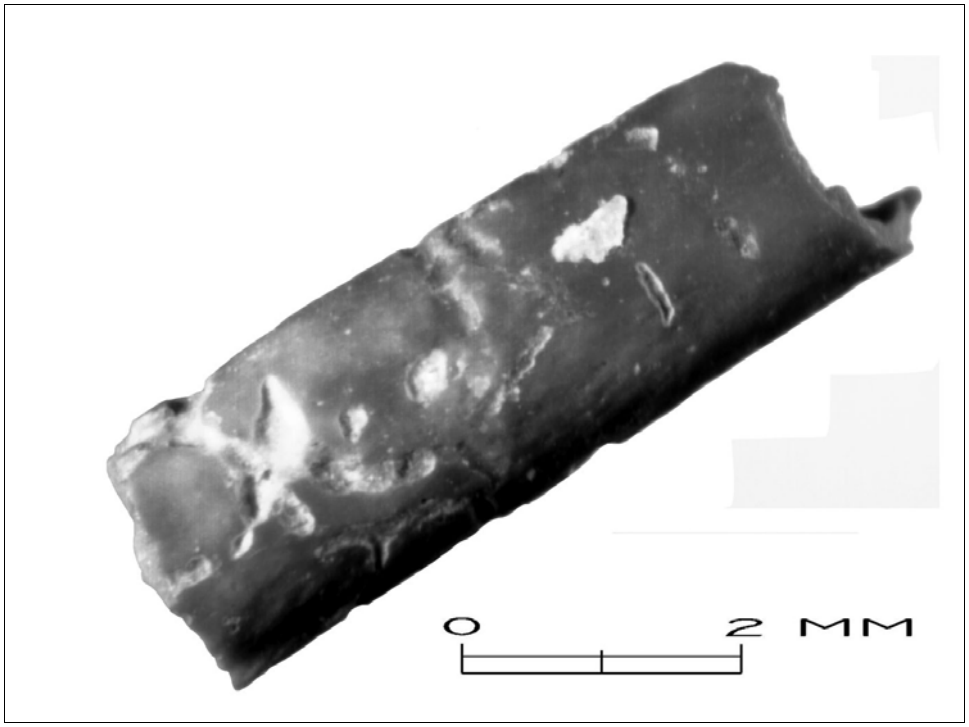


Figure 10.15. Surface-Channeled Shaft Fragment, Ambient Bone. Unidentified long bone shaft fragment with surface channels, some infilled with carbonate deposits. Channels are probably too large to represent fungal bioerosion. N109 E96 (92.05-92.00 m, bulk matrix, coarse fraction).

Shallow conical pits without overhanging edges resemble tooth pitting produced on small mammal bone by Bofi foragers of central Africa. Landt (2004) collected bones discarded (without passing through the digestive tract) after native foragers had gnawed the meat off. Prey included giant pouched rats and galagos, both weighing about a kilogram, and small murid rats and mice weighing less than a kilogram. Tooth pits on murid rat and mouse bone had a median diameter of 0.22 mm, mean of 0.47 ± 0.40 (range, 0.20-1.13 mm; Landt 2004:Table 5.5) and appear to resemble the pits seen on the Berger Bluff bone (see Landt 2004:Figs. 5.2, 5.4).

Cutmarks

Possible butchering marks have been found on only three bones from the bench deposits. One is a left distal humerus of a raccoon (*Procyon lotor*) that appears to have a spirally fractured proximal end. This specimen (Fig. 10.16) was embedded horizontally in the cutbank profile (in stratum 2C, at about 92.46 m; Fig. 4.57) and was struck by the trowel while profiling. The specimen is badly fissured and was removed in a block and treated with PVA at the Vertebrate Paleontology Laboratory. On the anterior surface is an oblique V-shaped cut mark about 9 mm long and 0.3 to 0.6 mm wide, taking the form of two narrow V-shaped marks at the distal end. This scar is partly filled with sediment and is coated with PVA, making it difficult to see whether it represents trowel damage or stone tool damage. Judging by what can be seen, it seems more likely that the scar was left by a stone tool, perhaps a chert flake. The opposite side of the bone, which was cleaned in the laboratory, has a great many smaller scars that were obviously left by a dental pick during cleaning. These are much shallower, shorter, and usually fresher appearing.

Another specimen consists of a small fragment apparently broken off one of two larger pieces of turtle plastron (Fig. 4.54) which was also struck by a shovel during cleaning of the cutbank profile. These turtle plastron fragments (from stratum 1, at 92.12 and 92.08 m) are also shown on the cutbank profile (Fig. 4.22). The small fragment bearing the cutmarks measures 11.3 mm x 9.5 mm across and is 2.6 mm thick. It has two parallel cutmarks on what may be the interior (?) surface (Fig.10.17). The marks are 3.0 mm and 3.4 mm long and are 0.2 mm wide, spaced 1.0 mm apart. Lime deposits and a few sediment grains are visible in the marks, which are deeply U-shaped in cross-section. These marks are not fresh and are believed to have been made with a chert flake.

The third specimen was found in N109 E96 (92.45-92.40) and consists of a very small, thin, somewhat curved bone, perhaps a skull fragment, from some very small unidentified animal (Fig. 10.18). It measures 4.0 mm x 6.2 mm across and on the convex face has a set of fine scratches, consisting of four subparallel scratches with a faint, divergent fifth scratch. The set of marks as a group measures 2.5 mm long and 0.4 mm wide. The scratches are very uniform in width and when measured with a calibrated optical microscope reticle are only about 0.02 mm wide. The origin of these marks is unknown. The bone fragment, although unidentified, appears to be from a small animal for which butchering would not be expected, and the marks are much finer than those generally left in butchering (as in the first two examples). They are definitely not a result of excavation damage. These marks are wider than human tooth scratch marks found by Landt (2004:Table 5.9) on the bones of murid rats and mice. His examples averaged 0.03 ± 0.03 mm in width.

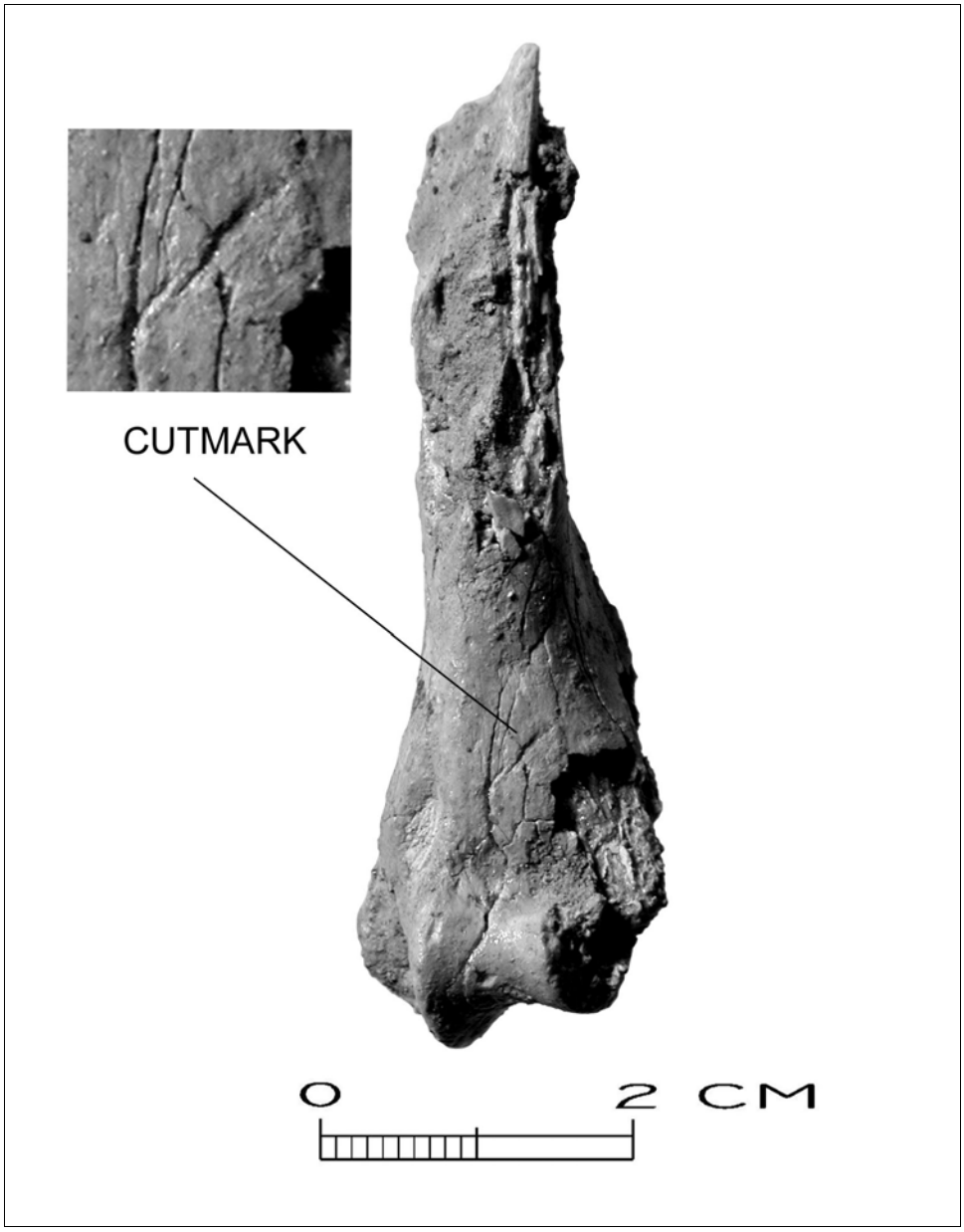


Figure 10.16. Cutmarked Raccoon Humerus. Left distal humerus fragment of *Procyon lotor* with oblique cutmark, perhaps made removing the pelt from the foreleg. Cutbank, stratum 2C, 92.46 m (lot B-156). See also Fig. 4.57.

Figure 10.17. Detail of Cutmarks on Turtle Plastron. Two parallel cutmarks on the interior (?) surface of a small fragment of turtle plastron. This fragment is one of six associated with two larger fragments identified as Emydidae (*Pseudemys concinna* or *Trachemys scripta*). All of the fragments (lot B-154) were found in the cutbank at the base of the stratum 1 exposure and are presumably all part of a single individual. The cutmarks are old and are definitely not excavation damage. This is the stratigraphically lowest bone known from the entire site. The location of the plastron is shown in Figs. 3.1 and 4.22 and an *in situ* photo of the largest fragment is shown as Fig. 4.54.

Although surface marks created by trampling and sedimentary abrasion (Fisher 1995:Figs. 8, 9) can sometimes mimic cutmarks left by humans, the cutmarks on the first two specimens (and possibly the third) appear to conform morphologically to marks left by stone tools (compare Fig. 10.17 to Fisher 1995:Figs. 1, 2a, 2b).

Chemical Dissolution: Limited Evidence, Ambiguous Sources

If bone fragments from the bench deposits are examined under magnification (10-70X), some evidence of chemical dissolution can occasionally be seen. Occasional extreme cases are seen where large areas of surface bone have been removed, exposing cancellous or fibrous bone structure underneath (Fig.10.19). These are uncommon, and many of them appear to be the poorly ossified ends of amphibian bones. Amphibian bones often have cartilage attachments at the end, and the adjacent part is poorly ossified and easily degraded by weak acids (Fig. 10.20). The same thing might be true for juvenile mammal bones. In other cases, there are small damaged areas on the articular ends of long bones, exposing chemically-rounded interior cancellous bone.

In cases like these, it is not always clear whether there has first been mechanical damage that exposed the cancellous bone to subsequent chemical attack, or if the damage is simply due to chemical removal of bone alone. A few bone splinters appear heavily weathered into irregular surface contours, perhaps by groundwater contact. A few more have broken edges that have subsequently been rounded and polished (Figs. 10.12, A; 10.21) and these are almost certainly due to gastric polish, but they are not particularly common.

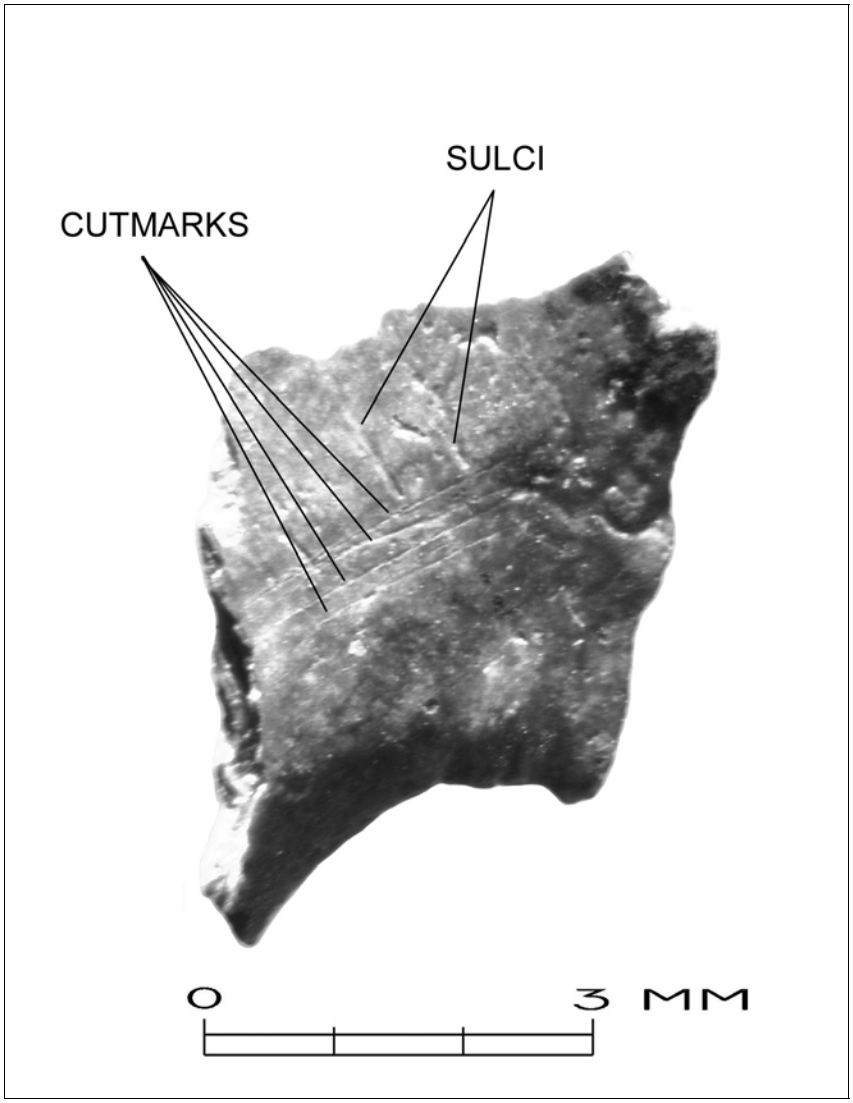


Figure 10.18. Unidentified Fragment with Cutmarks. Small flat bone fragment from unknown animal with four subparallel fine scratches. Larger grooves visible on surface are natural sulci. Ambient bone, N109 E96 (92.45-92.40 m, lot B-136.

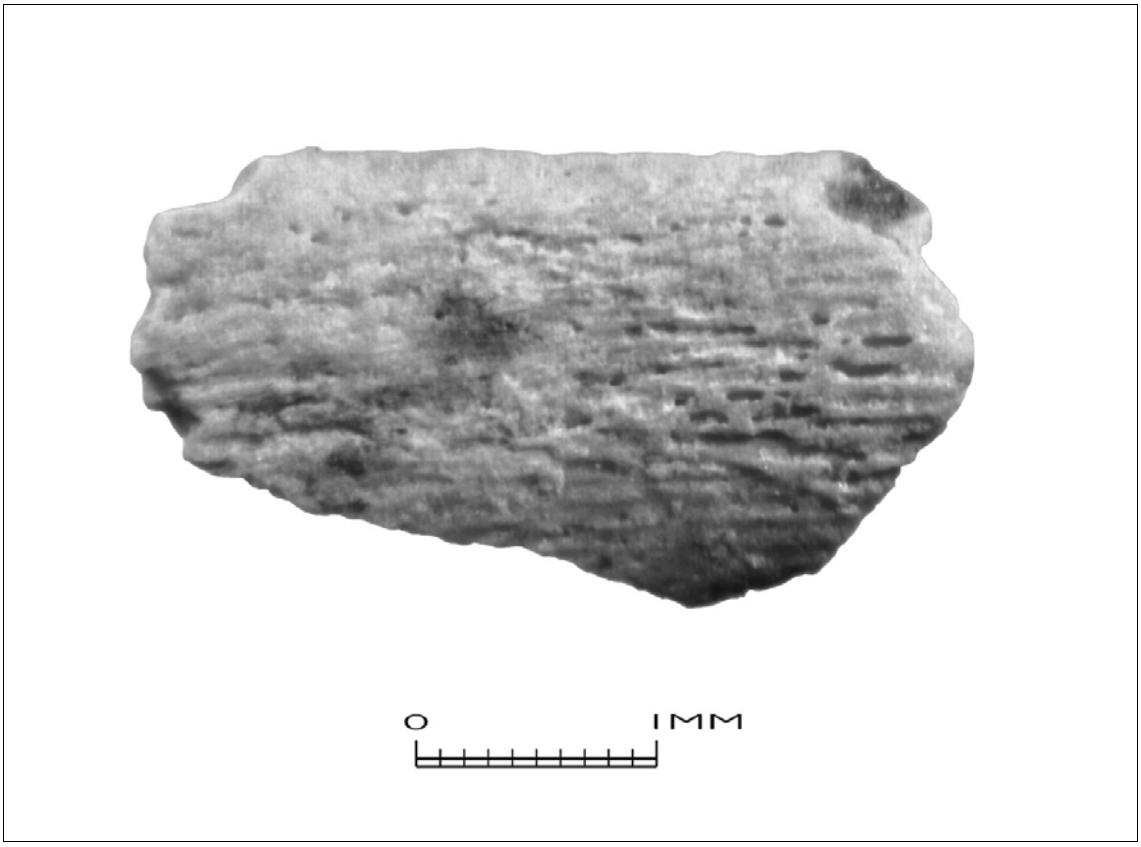


Figure 10.19. Surface-Corroded Bone Fragment From the Hearth Deposit. Chemical attack (either groundwater or stomach acids) appears to have removed surface bone from this small unidentified fragment, exposing the cellular structure underneath. N113 E98 (92.40-92.30 m, approximately upper 5 cm of level), lot B-107A.

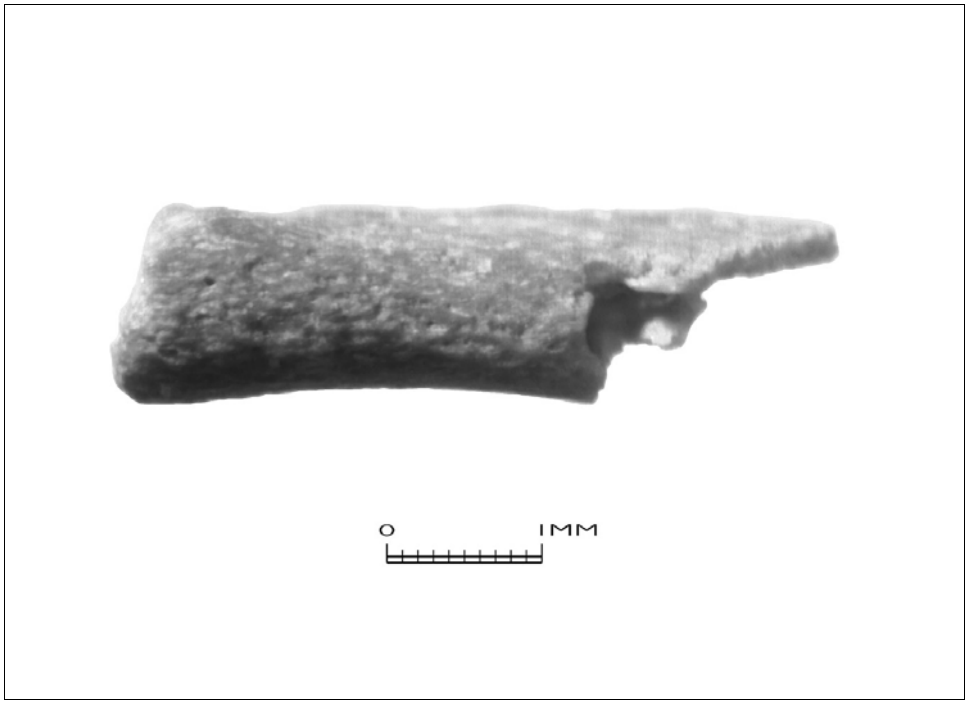


Figure 10.20. Corroded Long Bone Epiphysis (?) From the Hearth Deposit. Articular end (?) of unidentified bone fragment with chemically corroded surface. N113 E98 (92.40-92.30 m, approximately upper 5 cm of level), lot B-107A.

For both the hearth deposit and the ambient bone, mechanical breakage is far more pervasive and destructive than chemical alteration for the collection as a whole, and dissolution is in most cases not readily apparent except with magnification. Likewise, chemical alteration has not significantly reduced the identifiability of the elements, unlike mechanical breakage.

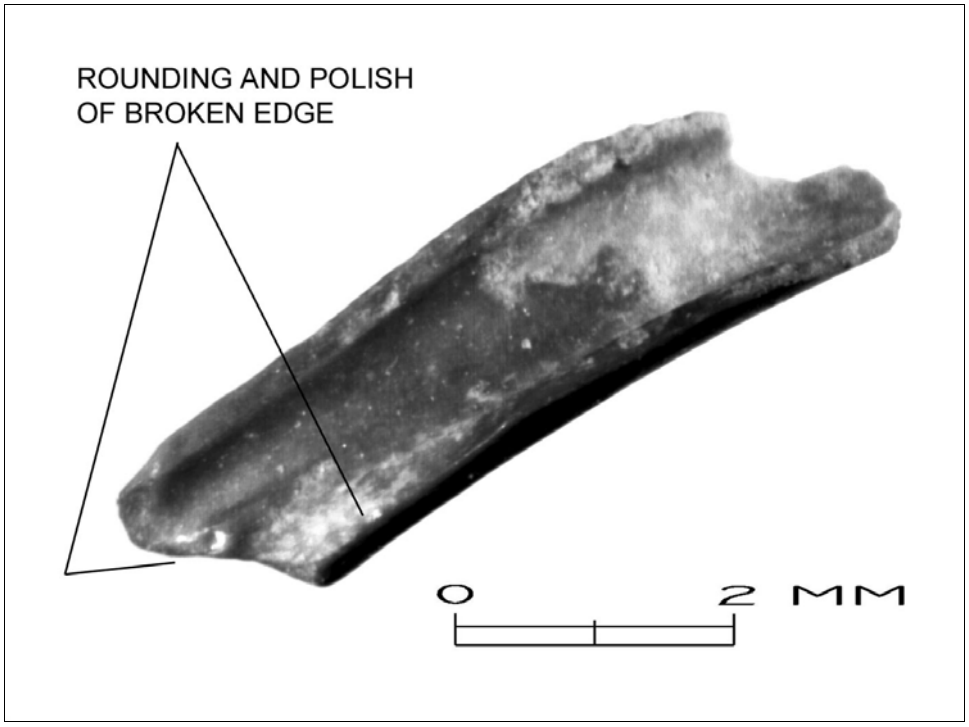


Figure 10.21. Edge-Polished Long Bone Fragment From the Hearth Deposit. Unidentified long bone splinter with edge rounding and (gastric?) polishing on one end. N113 E98 (92.40-92.30 m, approximately upper 5 cm of level), lot B-107A.

Neutral pH soils usually have calcium and phosphate concentrations close to saturation with respect to hydroxyapatite, and the rate of dissolution is therefore very much slower than the few years or so that would be the case for pure water, Therefore, most dissolution takes place when conditions change and become greatly undersaturated, either due to a reduction in pH or, more commonly, through recharging with fresh water. Such recharging happens in contexts with active hydrology, such as when close to the ground surface (percolating rainwater not yet equilibrated with soil hydroxyapatite), or in highly conductive soils (such as sands and gravels), which themselves are often found as alluvial deposits on flood plains and so on. This provides an adequate explanation for the general, if anecdotal, impression of excavators that bones from sandy deposits and/or flood plains are generally much more porous and friable (Hedges 2002:323-324).

The bench deposits are an exception to the above statement. While there was an active and frequent groundwater presence in the late Pleistocene and early Holocene, it was well saturated with carbonate from the Goliad Formation. Very alkaline environments can lead to increased calcium/phosphorus ratios in bone and ultimately to bone solubility (Linse and Burton 1990), but the bench deposits may have been circumneutral during most of their history.

Some of the bone has demonstrably been "digested," but whether the digestion is by groundwater or the stomach acids of predators is usually unclear unless some kind of abrasive polish is associated. Postburial alteration of bone involves some well-documented processes (reduced microporosity, increased macroporosity and crystallinity, uptake of calcium and uranium compounds; Hedges 2002; Hedges and Millard 1995) that are distinct from predator digestion, but not necessarily by surface inspection at 10-70X.

Fragmentation

Fragmentation of animal bone can occur from a variety of causes. Butchery or dismemberment of large or medium-sized animals by humans can result in fragmentation, but there are very few specimens from the bench deposits that fall into these size categories and might be candidates for this sort of process. All the rest of the bone is from small animals, and must have been fragmented by different processes. Ethnographic accounts show that when small animals are consumed by humans, they are normally cooked whole and either swallowed whole, roughly torn apart, or pounded on some sort of anvil. The murid rat and mouse bones studied by Landt were roasted, but had little damage (but recall that these were bones that were discarded, not ground up and passed

through the human digestive tract). He observes that "Even on the small MRM bones (N = 27), there is little fragmentation of whole bones, and most of the mastication damage is limited to the proximal and distal ends. This damage is discernible in crenulated edges that resulted in the removal of small amounts of cancellous bone tissue but did not result in the removal of epiphyseal ends" (Land 2004:67).

Fragmentation of bone from small animals can result from mastication by humans or other carnivores, from dismemberment by raptors, possibly from fluvial redeposition (but see the discussion in a later section of the hearth deposit), from sediment contraction and expansion during burial, or from excavation damage by archeologists. In the bench deposits, I believe the chief causes of breakage are mastication, sediment compression, and excavation damage. To a limited extent, these different sources can be discerned by examining the bone under magnification. If the bone was broken while it still retained significant amounts of collagen, a spiral break should result, resembling the broken edge seen in Fig. 10.12, A (Lyman 1994:320). This kind of break could result from mastication, pounding, trampling, or other sorts of perimortem damage. If the bone is broken after it has become decollagenated, usually by prolonged burial, either a clean transverse snap (for dense bones like long bones) or a jagged, irregular break might be expected (Lyman 1994:320), but in any case the surface of the break should have the same color as the rest of the bone. Bones broken during the bench excavations have rather light-colored, usually rough-textured breaks that make an obvious contrast with the rest of the bone. Careful microscopic examination of the collection from the bench shows that there are all three kinds of breaks, singly and in combination. Some fragments, for example, have both old snaps and fresh excavation damage. Microscopic examination (up to 70X) very often shows sediment grains or carbonate deposits (or occasionally

manganese deposits) in the medullary interiors of bone fragments or covering broken edges, indicating that the bones were already broken before they were excavated.

Perhaps in most cases, fresh breaks can be reliably distinguished from old ones, but distinguishing mastication from sediment compression breakage is less certain. Smoke and Stahl (2004) studied sediment compression breakage of *Peromyscus leucopus* (white-footed mouse) bones, but since they used green bone in a gravel matrix, the results have limited relevance to Berger Bluff. Their study showed that gravel compaction produces extensive breakage of bones extracted from screech owl pellets, but much less breakage of bones that were artificially macerated.

Measurement of Size Grading

Several lots representing both the hearth deposit and ambient bone have been measured. For the hearth deposit, lots B-105, B-107 and B-149 have been measured, while lots B-106 and B-107A have not (no bone was found on the 1/4-inch screen from these levels). Fragments were measured to the nearest tenth of a millimeter with a pair of sliding vernier calipers marked in 0.05 mm increments. Measurements were made of the longest dimension on each fragment, regardless of whether the long axis corresponded to the anatomical orientation of the bone. In some cases the dimension measured was actually diagonal to the natural orientation of the bone. For the ambient bone, the most accessible and representative lots are from the bulk matrix samples passing the 1/4-inch screen in N109 E96, so a few of the lots that have been picked were selected for measurement (no lot numbers have been assigned for these yet). Lots from the 92.05-92.00 m, 92.15-92.10 m (SW half, NE half), and 92.35-92.30 m levels were selected for

measurement, and bones found on the 1/4-inch screen (there are only three from these levels) were included. Measurements of the ambient lots were made measured to the nearest tenth of a millimeter with a pair of plastic dial calipers marked in 0.10 mm increments. The difference in measuring instruments is not thought to have any significant effect on comparing the two categories of bone. A total of 1096 fragments has been measured, and the results are shown in Table 10.14 and Figure 10.22.

The median size for all fragments measured from the bench deposits is just 3.10 mm and is identical for the hearth deposit and ambient bone. The mean for the ambient bone is slightly smaller, probably because of slightly more rigorous collection technique. The size distributions for both categories of bone are right-skewed and are probably very slightly truncated on the left due to failure to measure bits of bone smaller than 0.8 mm (Figure 10.22). Figure 10.23 shows the array of bone in lot B-107A. This lot has not yet been sorted, identified or measured, but it is entirely comparable in appearance and composition to the lots that have already been studied.

As the illustration shows, most of this bone is smaller than 1/4-inch mesh, but the recovery techniques used were effective in capturing it. The largest bones recovered from the bench deposits are the raccoon humerus fragment (Fig. 10.16), 6.56 cm long, and a large turtle (Emydidae) hypoplastron fragment 7.8 cm long, both recovered from the cutbank. However, neither of these is included in the measured lots, so neither appears in Figure 10.22, and it is likely that there are a few unidentified fragments in the bench from animals larger than raccoons or turtles.

The frequency profiles shown in Figure 10.22 are not particularly diagnostic of anything except friability. The leptokurtic, somewhat right-skewed shape of the curve is typical for size distributions of all kinds of friable material recovered in archeological excavations (potsherds, firecracked rock, and glass fragments, for example). I have seen no published size curves for animals of comparable size, but there are a few published frequency curves for bone fragments derived from large animals (Bar-Oz *et al*. 2005:Fig. 13.4; Harrell 1988:Fig. 1; Lyman 1994:Fig. 8.10; Watson 1972:Fig. 1), and these have the same general shape, differing mainly in the units used for the X axis.

Table 10.14. Size Grading of Bone Lots.

Ambient bone [92.05-92.00, 92.15-92.10 (SW half, NE half), and 92.35-92.30 m levels]	
mean	3.48 mm
median	3.10 mm
standard deviation	2.67 mm
skewness*	13.01
range	1.1-50.0 mm
N	417
Hearth deposit (Lots B-105, B-107, and B-149)	
mean	4.00 mm
median	3.10 mm
standard deviation	2.96 mm
skewness*	2.15
range	0.8-20.9 mm
N	679
Combined samples	
mean	3.81 mm
median	3.10 mm
standard deviation	2.86 mm
skewness*	5.50
range	0.8-50.0 mm
N	1096

* As computed in Microsoft Excel 97.

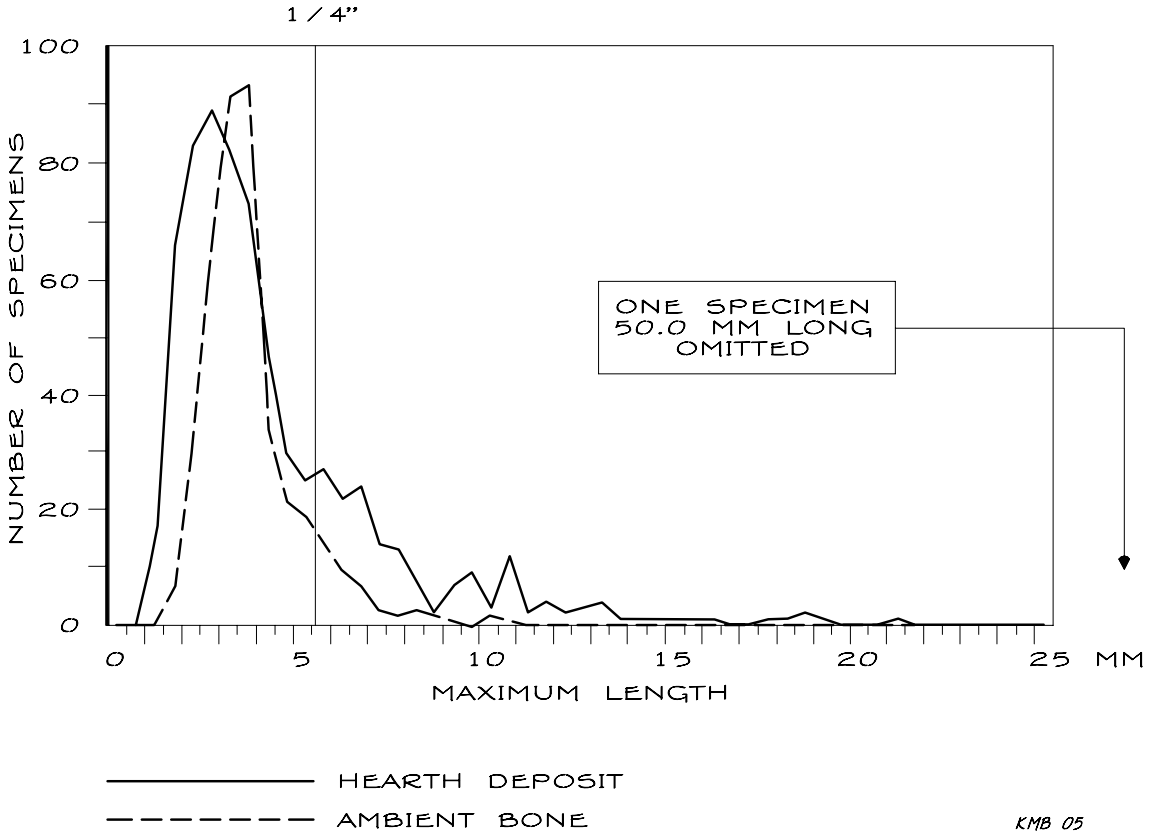


Figure 10.22 Size Distribution of Ambient and Hearth Deposit Bone Fragments. Samples of ambient bone (N109 E96, 92.05-92.00 m, 92.15-92.10 m, 92.35-92.30 m; bulk matrix, coarse fraction and ¼-inch screen, N = 417) and hearth deposit bone (lots B-105, B-107, and B-149; N = 679) are measured to the nearest tenth of a millimeter for maximum length and plotted here. One large ambient bone fragment falls off the graph and has been omitted.

MEASURES OF ABUNDANCE

Rational Basis for Counting

The animals represented in the hearth deposit are believed to have arrived at Berger Bluff in the digestive tract of a predator, deposited as coprolites (this issue will be discussed later in much more detail). Whether the entire carcass was deposited depends

on the particular consumption and excretion history of each animal unit, but in any case the animals represented are so small that it is unlikely they were extensively butchered and shared among multiple consumers. There is, then, a fairly high probability that bones from the entire carcass are present in the hearth deposit (or to put it another way, that there has been little off-site bone loss), although since much of the bone bed probably remains unexcavated, the sample is incomplete.

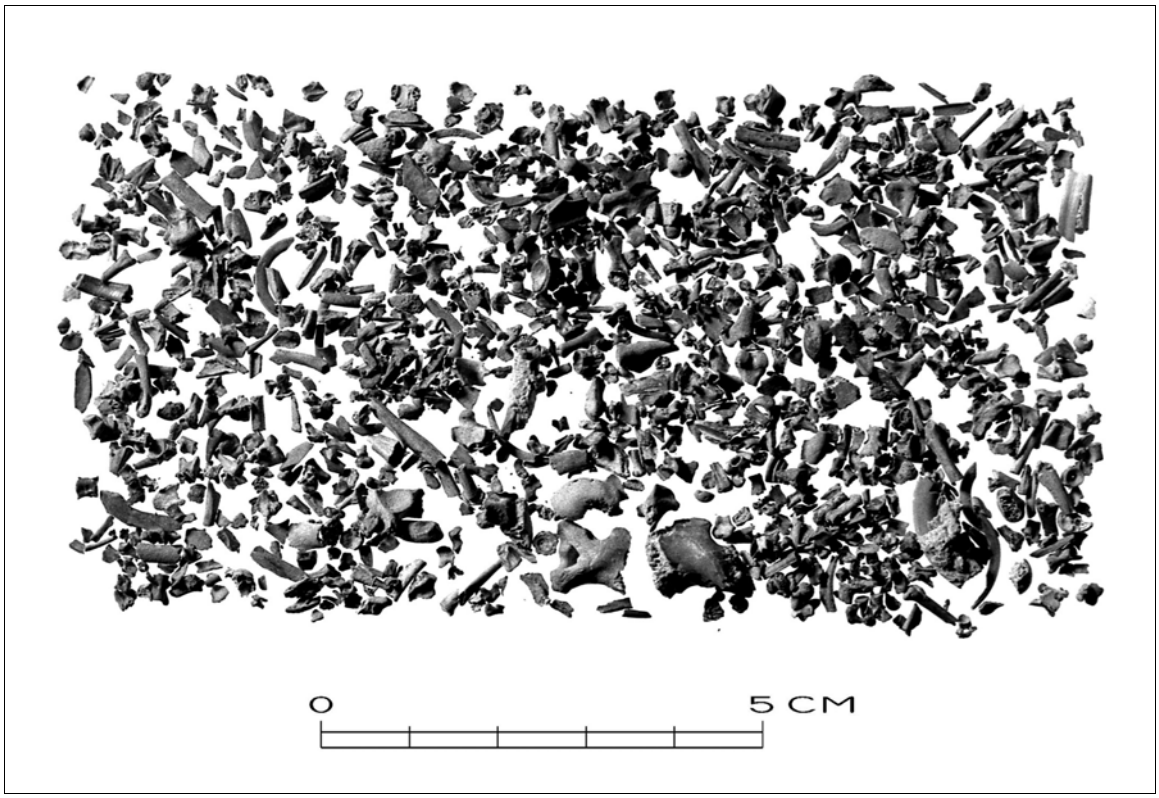


Figure 10.23. Fragmented Animal Bone From the Hearth Deposit. Unsorted bone fragments from N113 E98 (approximately upper 5 cm of 92.40-92.30 m level), lot B-107A. Fragments picked in December, 1989 from loose matrix wet-sieved by Boyce Cabaniss. This view is representative of the size and degree of fragmentation of both the hearth deposit and ambient bone. These fragments have not been identified or measured yet. Compare with Walker (1975:Fig. 1).

For the ambient bone, the situation is different. Most of this bone is thought to represent what Lyman calls "background scatters" (Lyman 1994:189-191) – animals that may have died on the site, been deposited in coprolites, or possibly arrived as clastic material in overbank flooding (although there is no evidence of fluvial abrasion). For this material, the animals may or may not have arrived on the site as complete carcasses – the issue is problematical. These points need to be kept in mind when considering the following discussion.

In tallying the bone fragments from the bench deposits, a reasonable set of goals might include:

1) estimating the relative proportions of the different taxa;
2) making at least an order-of-magnitude estimate of the number of individuals present in the hearth deposit.

Various measures of abundance have been proposed for use in zooarcheology, and the literature on their merits or defects is extensive. Many of them are designed to deal with situations where large animals are butchered in the field and returned to a base camp for further processing, and consequently have little relevance to the present study. The principal measures are:

NISP (number of identified specimens): simply the frequency of elements or fragments of any kind that can be assigned to a particular taxon.

MNI (minimum number of individuals): the minimum number of animals necessary to account for the elements or fragments in a particular provenience unit (site, stratum, arbitrary level, or other three-dimensional unit). Determined by counting the most abundant element (for example, left distal humerus), often refined by noting differences in size or age of individual.

Other measures (not used in the present study) include:

MAU (minimum animal units): specimen counts divided by the frequency of the element in a skeleton of that particular taxon.

MNE (minimum number of elements): see Lyman (1994:102-104).

WAE (weighted abundance of elements): see Hesse (1982:166-167).

The most useful discussions of the NISP and MNI measures are found in Grayson (1984) and Klein and Cruz-Uribe (1984). There are several well-known problems with using NISP as a measure of abundance. Fragmentation of bone (as in the Berger Bluff case) tends to drive up the specimen counts, inflating the apparent number of animals, although if fragmentation is thorough enough, it can reduce identifiability to the point that it begins to have the opposite effect and the number of identifiable specimens will level off (Marshall and Pilgram 1993; Cannon 2005). Different taxa may also have different numbers of bones, so taxa that have the highest number of easily identifiable elements may be overrepresented. In the Berger Bluff assemblages, the most

problematical taxa are those that are likely to be represented mostly by vertebrae – the snakes, and to a lesser extent, salamanders and fish.

To take a graphic example, there are 25 complete snake vertebrae plus four vertebral fragments in the identified part of the hearth deposit, and (a rough estimate) perhaps another three dozen in lot B-107A not yet sorted or identified. Thus, there are probably at least 62 snake vertebrae, perhaps more or less. Since colubroid snakes in general have about 200 or more vertebrae per individual (Romer 1956:229), without further information we cannot say if these 62 vertebrae represent 62 distinct snakes or perhaps a fourth of one single snake. Fortunately, some of the vertebrae are identifiable at least to the family level and below, showing that in fact there are several different kinds present.

The principal objection raised by Grayson against MNI as a measure of abundance is the problem of *aggregation*. To take a heuristic example, suppose that the most abundant element in a site for some particular taxon is the left humerus, and there are four distal and two proximal fragments. If the entire site is the basis for computing MNIs, then the four left distal humeri provide a minimum number of four individuals.

On the other hand, suppose the uppermost stratum of the site has only three distal fragments, and the lowest stratum has one distal and two proximal left humeri, and likewise suppose these two strata are sufficiently separated that mixing is unlikely. In that case, the upper stratum would yield an MNI of three and the lower of two, for a total of five. As Grayson (1984:27-49) points out, the number of provenience units (strata, arbitrary levels, excavation squares or areas) that are used to subdivide the collection and

the assumptions underpinning these subdivisions have a profound effect on not just the computed number of individuals, but the ratios between different taxa.

Because the hearth deposit is believed to represent a single relatively short-term depositional event, it is appropriate to aggregate all the lots of bone shown in Fig. 10.5 for a single MNI calculation. For the ambient bone, the situation is somewhat different. The bone fragments come from eight different excavation units, scattered through fill that accumulated over the course of a couple of thousand years, and it seems unlikely that elements from stratum 2D in the westernmost units could be part of the same individuals as elements from stratum 1 in the easternmost units. In this case, it seems reasonable to use depositional strata as the units of aggregation, even though the geological depositional events and the taphonomic depositional events need not have any particular relationship.

Accordingly, I have calculated MNIs for the ambient bone in two different ways: aggregating elements across the entire site ("MNI SITE") and aggregating them by strata ("MNI STRATA"). As expected (and as in the examples given by Grayson) aggregating by strata produces somewhat higher minimum numbers. Where possible, I have also taken into account animal size and presence of juveniles in calculating MNIs. For example, among the bird material from the hearth deposit are sparrow-sized, blue jay-sized, and quail-sized elements. None have been identified taxonomically, but three sizes of birds seem to be represented, and I believe at least three individuals are present.

Taxonomic uncertainty may also reduce the precision of MNI counts as well as the total MNI count. For example, Lot B-106 has a single *Cryptotis parva* molar and a

partial edentulous left mandible that could only be ascribed to Soricidae. These are probably the same animal, but even if the mandible is listed as *Cryptotis parva*, the MNI will remain at one. In this case, uncertainty changes nothing.

The salamanders from the hearth deposit are a more nettlesome problem, however. It is highly likely that only one species, *Ambystoma texanum*, is represented in the entire site. However, some fragments were identified as *Ambystoma texanum*, others as *Ambystoma* sp. (included are three vertebrae slightly larger than typical *A. texanum* vertebrae), and still others as "Salamander, unidentified." Classing all of these as *A. texanum* and computing MNIs accordingly would be too presumptive, perhaps. Keeping them in separate categories produces a different set of MNI counts. No MNI values are provided for generalized categories like "Salamander, unidentified" or "Rodent, unidentified," because more than one taxon might be represented in categories like this. MNI counts are meaningless for such taxonomically vague categories, so the symbol N/A (not applicable) is used in the specimen tables.

Rabbits from the ambient fauna provide another example of multiple levels of uncertainty. A single distal metapodial classed as "Leporidae" comes from a large rabbit, perhaps swamp rabbit or blacktailed jackrabbit (1.5-4 kg body weight), and there is also a scapula fragment resembling blacktailed jackrabbit. Most of the remaining material comes from smaller rabbits than these. Eastern cottontail (*Sylvilagus floridanus*, 1-2 kg) seems most plausible, but most is simply classified as "*Sylvilagus* sp.". Cabaniss also classified some of the material as *Sylvilagus* cf. *S. audubonii* or *S. floridanus*. *Sylvilagus audubonii* is the desert cottontail, a xeric upland chaparral species whose present range in west Texas approaches no closer to Berger Bluff than LaSalle County (Schmidly

2004:463). Based on its present range, desert cottontail seems implausible for the Berger Bluff material, but Cabaniss felt it was a reasonable match from an osteological perspective. In summary, although the rabbit material is listed under four different categories, it seems rather likely that there are only two species, a large rabbit (uncommon, perhaps jackrabbit) and a smaller one (common, perhaps eastern cottontail). Some of the material listed only as *Sylvilagus* comes from the same excavation levels (or adjacent ones) as that classified as *S. audubonii/S. floridanus*. Surely these must represent parts of the same individuals. I have listed suggested MNI estimates for the *Sylvilagus* sp. material even though it is unidentified because there are simply too many specimens to disregard.

Grayson and others have shown that the relationship between NISP and MINI is usually curvilinear, or is linear when plotted on logarithmic axes (Bobrowsky 1982; Grayson 1984:49-68). In some cases, the relationship may be linear. For the bench deposits, the logarithmic function is weak ($r^2 = 0.46$, plotted on linear axes) for the hearth deposit, slightly stronger ($r^2 = 0.65$) for ambient bone when aggregated by strata, and a linear function yields slightly higher r^2 values for both. The corresponding correlation coefficients are considerably lower than those shown by Grayson (1984:Table 2.18), perhaps because he uses larger samples. Some analysts have suggested the true number of original individuals producing the bone assemblage lies somewhere between the NISP and MNI values, and for the Berger Bluff case, this is almost certainly true. It is also clear that the discrepancy varies by taxon. For the least shrew elements mentioned above, the NISP (2) and MNI (1) are not far apart. For the salamander remains, the minimum numbers probably underestimate the original number of individuals to a significant degree.

THE AMBIENT FAUNA

Table 10.15 lists counts for the identified portion of the ambient fauna. As the table shows, the total minimum number of individuals is rather low (less than four dozen), partly because the "background scatter" of bone in the site is only moderately abundant, but chiefly because most of the lots analyzed were not collected with techniques designed to recover small animal remains. As I have remarked earlier, where fine sieving was used to process fill from unit N109 E96, much larger quantities of small bone fragments were recovered, but nearly all of this bone has yet to be identified and is not listed in Table 10.15.

When all of the bone has been picked from the N109 E96 matrix and identified, it will be possible to compare the bench deposits against other early floodplain sites where fine sieving has been employed, such as the Armstrong, Aubrey, Lubbock Lake, and Wilson-Leonard sites, to see how recovery rates and species composition compare. The bench deposits can supply this information, but studies are not yet complete.

Figures 10.8 to 10.10 show the simplified taxonomic composition by NISP, while Fig. 10.24 shows the composition by MNI. Both kinds of diagrams are similar. The assemblage consists almost entirely of small animals, but there are a handful of bone fragments from large animals (possibly deer), and a number of specimens from medium-sized animals (mostly rabbits and a couple of raccoon specimens). Rabbits, gophers, turtles, and salamanders are the most abundant taxa. Jackrabbit, cotton rat, raccoon, unidentified large animals, turtles, water snake, and gar are all ambient taxa not known from the hearth deposit (Table 10.1). Bone fragments probably entered the deposits

through several different pathways. Some (for example, rabbit, raccoon, and some of the deer-sized fragments) may be the result of on-site butchering by humans. Others may have been deposited in human coprolites, but not in concentrated latrine areas like the hearth deposit. Some of the small animal fragments may come from animals that died naturally on the site, and it is possible that a few fragments (particularly the smaller fish vertebrae) might have been deposited as clastic material during flooding, although as I have pointed out earlier, there is no evidence of fluvial abrasion on the bone.

The rabbits and most of the small mammals likely were obtained in brushy or open to parkland habitats in the adjacent sandy uplands. Raccoons and moles may have been obtained on the Coleto Creek floodplain, the moles perhaps in less heavily wooded parts. Gophers, woodrats, small perching birds, and voles might have originated either in the uplands or less heavily wooded parts of the floodplain. The fish, water snake, frogs and toads, salamanders, and turtles are diagnostic of standing water sources and would have been found in (or for some groups, near) the creek.

In general, there is a heavy representation of non-mammals from riparian habitats and mammals from upland habitats, with the riparian animals roughly twice as abundant as the upland animals, whether measured by NISP or MNI. Most of the riparian taxa are heavily dependent on reliable water sources, especially during breeding season.

Table 10.15. Ambient Fauna: Measures of Abundance.

	NISP	MNI SITE	MNI STRATA
Fish, unidentified	12	2	2
Snakes			
Virginia striatula	1	1	1
Nerodia sp.	1	1	1
Snake, unidentified	2	N/A	N/A
Lizards, unidentified	1	1	1
Turtles			
cf. *Gopherus hexagonatus*	1	1	1
cf. *Sternotherus odoratus*	1	1	1
Kinosternidae, unidentified	1	1	1
Emydidae	8	1	1
Turtle, unidentified	4	1	3
Birds, unidentified	5	1	3
Rabbit or bird	10	N/A	N/A
Amphibians			
cf. *Bufo* sp.	2	2	2
cf. *Rana berlandieri*	6	3	3
Rana catesbeiana	1	1	1
Frog/toad, unidentified	2	N/A	N/A
Salamanders			
cf. *Ambystoma* sp.	6	1	3
Salamander, unidentified	2	N/A	N/A
Mammals			
Cryptotis parva	1	1	1
Scalopus aquaticus	1	1	1
Geomys sp.	21	5	6
cf. *Dipodomys ordii* or *D. compactus*	2	1	1
Chaetodipus hispidus	2	1	2
Onychomys leucogaster	1	1	1
Sigmodon hispidus	1	1	1
Cricetidae, unidentified	1	N/A	N/A
Neotoma sp.	1	1	1
P. pinetorum or *M. ochrogaster*	4	1	3
cf. *Sylvilagus audubonii* or *S. floridanus*	4	1	2
Sylvilagus sp.	11	2	3
cf. *Lepus californicus*	1	1	1
Leporidae	1	N/A	N/A
Procyon lotor	2	1	1
Rodent, unidentified	18	N/A	N/A
Small mammal, unidentified	107	N/A	N/A
Mammal, unidentified	4	N/A	N/A
Animal, unidentified	338	N/A	N/A
TOTALS:	587	35	45

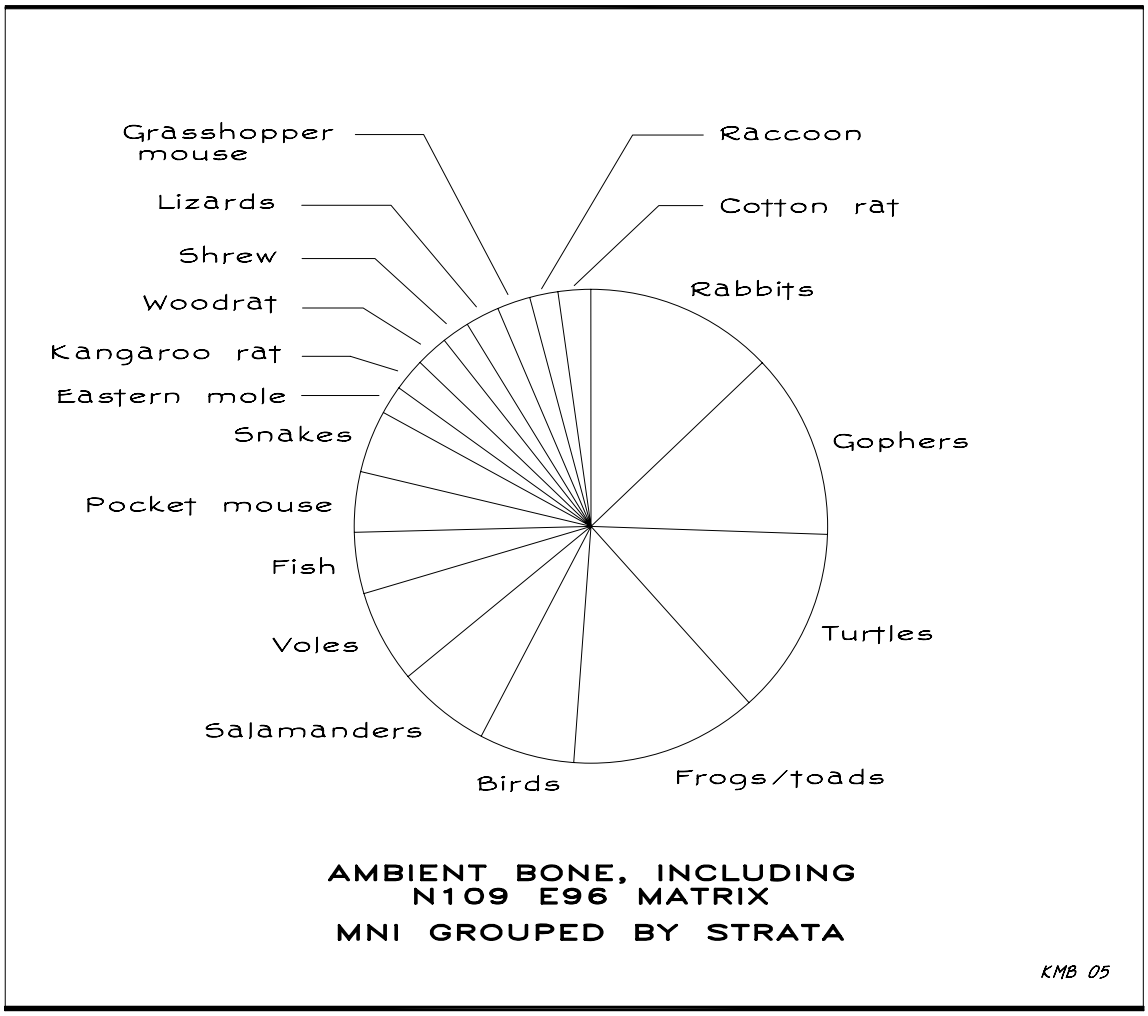


Figure 10.24. Ambient Bone: Taxonomic Composition by Minimum Number of Individuals. Relative proportions of major vertebrate categories are ranked by MNI (Note: for matrix samples, only three levels are included, and not all the bone from the levels is tallied). The minimum numbers shown here are low – the first four categories have an MNI of only six apiece. Compare with Figure 10.9.

Heat-Altered Ambient Bone

Table 10.16 lists specimens with evidence of heat alteration in the analyzed portion of the ambient bone assemblage. Artiodactyls (probably white-tailed deer), unidentified gopher-sized animals, rabbits (Fig. 10.25), and a turtle appear to be represented. There are also examples in the unanalyzed portion of the ambient assemblage (Figs. 10.11, 10.26).

Table 10.16. Heat-Altered Ambient Bone.

Unit	Level	Taxon	Description
N109 E103	93.14-92.90	Unidentified animal	2 calcined fragments from deer-sized animal (lot B-1)
N109 E103	92.90-92.85	Unidentified animal	1 calcined cancellous bone probably from rabbit-sized or larger animal (lot B-3)
N110 E102	92.20-92.15	Unidentified animal	7 small splinters of charred antler (lot B-54)
N110 E102	92.10-92.05	Unidentified animal	1 charred antler splinter (lot B-57)
N110 E102	91.95-91.90	Unidentified animal	1 burned long bone shaft fragment from *Geomys*-sized animal (lot B-62A)
N110 E102	91.70-91.65	Unidentified animal	1 small sliver of charred antler (lot B-69)
N111 E101	91.95-91.90	Unidentified animal	1 calcined pelvis (?) fragment from *Geomys*-sized animal (lot B-88A)
N109 E96	92.50-92.45 bulk matrix	cf. *Lepus californicus*	1 calcined fragment, border of glenoid fossa, rt scapula (lot B-157)
N109 E96	92.45-92.40	*Sylvilagus* cf. *S. audubonii* or *S. floridanus*	2 proximal tibia fragments, calcined, cracked and heat-warped (lot B-136)
N109 E96	92.40-92.35	Unidentified animal	1 charred long bone shaft fragment (lot B-137)
N109 E96	92.25-92.20	Turtle (Kinosternidae?)	2 slightly heat-discolored carapace fragments (lot B-143)

See also lot B-133

Juveniles

Osteological evidence of juvenile animals is surprisingly uncommon. Only four specimens are known from the analyzed portion of the ambient bone. One is the shaft and part of the distal end (with an unfused epiphysis) of a very gracile left tibia that compares well with *Dipodomys ordii* (Ord kangaroo rat) or possibly Gulf Coast kangaroo rat (*Dipodomys compactus*). This specimen (N109 E96, 92.35-92.30 m, lot B-140) was found in the fill of Feature 7, a small pit (Figs. 4.39, 4.49). Another is the centrum of a caudal vertebra (with unfused epiphyses) from an unidentified raccoon-sized animal (N112 E97, 92.25-92.20 m, lot B-123). There are also an upper incisor and an unidentified cheek tooth probably from a pocket gopher, *Geomys* sp., in lot B-158 (N109 E96, 92.70-92.65 m, bulk soil sample, coarse fraction).

Dipodomys ordii has a rather long breeding period, almost seven months (Garrison and Best 1990:4); animals from Utah in captivity may produce up to five litters per year (Egoscue, Bittmenn and Petrovich 1970:Table 1). In the Panhandle and Oklahoma, young might be born from August to February or later, and young individuals could appear anytime in fall, winter or spring (McCulloch and Inglis 1961; Hoditschek and Best 1983). After birth, juveniles grow rapidly for the first 28 days, then more slowly out to the 70th day (Smith, Richins and Jorgensen 1978). *Dipodomys compactus* is less well known, but may breed in the summer (Baumgardner 1991:3).

Attwater's pocket gopher (*Geomys attwateri*) breeds October to June with peaks in December-January and April-May, producing at least two litters per year (Schmidly

2004:334). The Texas pocket gopher (*Geomys personatus*) may breed year-round (Schmidly 2004:342).

Bone Fragments From Large Animals

Fragments from large animals (larger than a raccoon or jackrabbit) are so uncommon that they can be described individually here. All are found in the ambient assemblage, none in the hearth deposit. Small fragments of thoroughly charred long bone are almost impossible to distinguish from antler, so the identity of some of the small slivers listed below is uncertain.

Lot B-1, N109 E103 (93.14-92.90 m). Two small fragments of thoroughly calcined long bone from a deer-sized animal. Both are shades of black, medium to light gray, and white. One fragment is 1.68 cm long, 7.8 mm wide, 3.2 mm thick with carbonate deposit on a broken edge. The other is 1.40 cm long, 7.5 mm wide, 4.3 mm thick. These appear slightly thinner than the midshaft of a modern white-tailed deer tibia.

Lot B-29, N109 E103 (92.05-92.00 m). Very small triangular splinter of beige (8YR 7.5/4) matte-textured bone, from some animal larger than a small mammal. Length, 1.19 cm, width 4.4 mm, thickness 3.0 mm. One fresh (?) break, plus old break with carbonate deposit (dry bone fracture?).

Lot B-3, N109 E103 (92.90-92.85 m). Small irregular fragment of thoroughly calcined cancellous bone from unknown animal, rabbit-sized or larger. Bone is white to light gray-brown (10YR 7.5/1.5), 1.33 cm long, 8.3 mm wide, 5.6 mm thick.

Lot B-31, N109 E103 (92.00-91.95 m level, found at 91.95 m?). Long bone splinter 4.63 cm long, maximum width 0.97 cm, maximum thickness 4.5 mm. A fairly good match with the midshaft of a modern white-tailed deer tibia (wall thickness 4.0-6.3 mm); has green bone fracture on one end, excavation damage on the other. Exterior surface has laminar flaking, as if weathered. Bone is light beige (10YR 8/3 to 7.5 YR 5.5/5) and appears decollagenated (Fig. 10.27, A). A second fragment (Fig. 10.27, B) resembles the first but does not join, has dry bone fractures on both ends; 17.9 mm long, 10.4 mm wide, 3.1 mm thick. Found at 91.992 m (?), these two fragments were found in the same area but separated vertically by about 4 cm.

Lot B-33, N110 E102 (93.08-92.90 m). Long bone shaft fragment 2.52 cm long, 1.31 cm wide, 1.9-3.1 mm thick. Green bone fracture along one edge. Interior surface has thick carbonate deposit. Exterior surface has hairline cracks oblique to long axis of element as well as raised bone texture (probably from weathering), also oblique. Exterior is light beige (6YR 7/4). This could possibly be a rib fragment from a deer-sized animal. Fig. 10.27, D.

A second smaller fragment (Fig. 10.27, C) is 14.9 mm long, 6.6 mm wide, 2.2 mm thick. A small flat bone fragment (unknown element and animal, larger than a small mammal). Could be a medium or large-sized animal. Bone is cream-colored (7.5YR 9/3) with heavy chemical dissolution of all surfaces, because of which original type of break cannot be determined.

Lot B-54, N110 E102 (92.20-92.15 m). Seven small splinters of charred bone or antler, probably one specimen that shattered during excavation. the largest is 1.33 cm long, 3.2 mm wide, 1.9 mm thick. Exterior surface is light brown (7.5YR 4.5/3.5), charred interior is brown-black (7.5YR 3/1); Fig. 10.27, E.

Lot B-57, N110 E102 (92.10-92.05 m). One charred bone or antler splinter, probably related to the specimens in lot B-54. Light yellow-brown (7.5YR 7.5/2.5) with brown-black interior (7.5YR 2.5/0) and surface manganese stains, 1.56 cm long, 3.3 mm wide, 3.0 mm thick. Fig. 10.27, G.

Lot B-69, N110 E102 (91.70-91.65 m). Small splinter of charred bone or antler, 1.30 cm long, 3.7 mm wide, 2.5 mm thick. Cream-colored and black, with manganese stains; Fig. 10.27, H.

Lot B-108, Plotted bone fragment at N113.64 E98.86, 92.14 m. Very small chip from cortical wall of long bone (?) of raccoon-sized or larger animal. Matte-textured beige bone with yellow (uranium oxide?) stain. Has dry bone fracture and very slight polish, but not on broken surface. Small exterior pit. Length 8.9 mm, width 4.8 mm, thickness 1.7 mm.

Lot B-141, N109 E96 (92.30-92.25 m). Very small tabular section of the cortical wall of a long bone (?) from a deer-sized animal (Fig. 10.27, F). Closely resembles lot B-31 specimens, but smaller fragment. Length 8.3 mm, width 5.6 mm, thickness 3.1 mm. Surface is cream to beige (7.5YR 8/3.5) showing chemical dissolution and manganese stains, with a chalky appearance. Breakage is probably dry bone fracture.

In addition to the above, there is a probable carapace fragment from a large extinct tortoise (see the following text section).

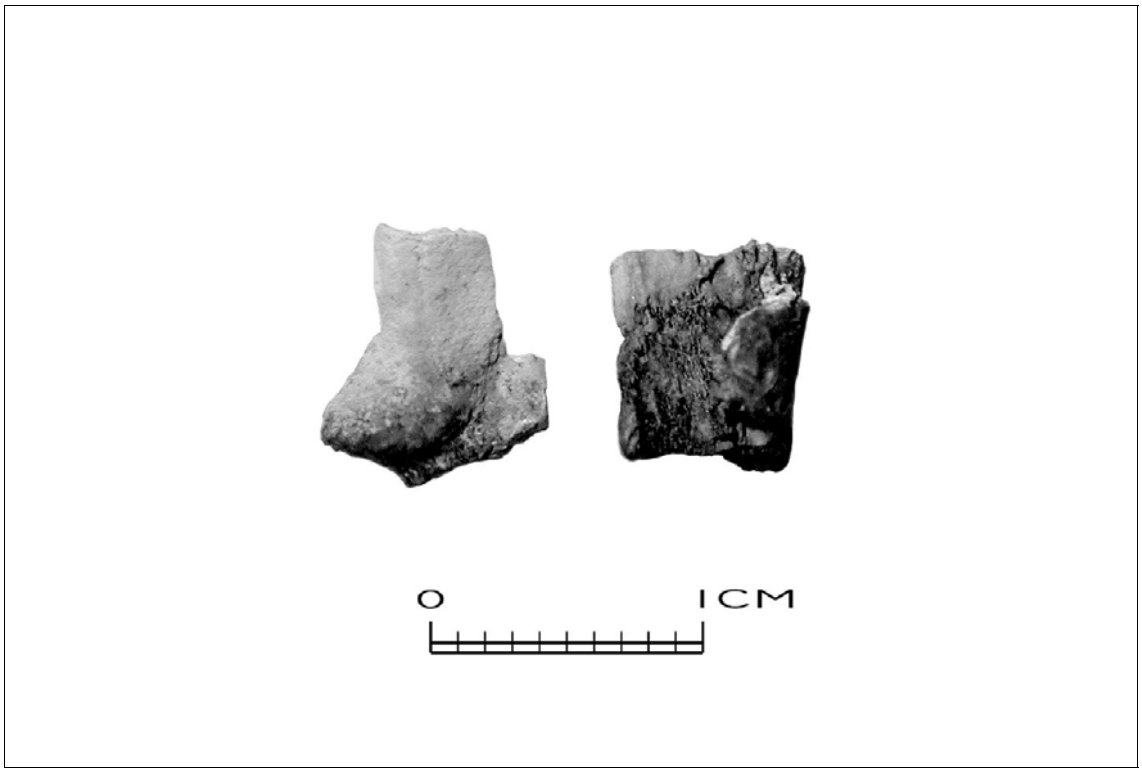


Figure 10.25. Calcined Rabbit Bones From the Ambient Fauna. *Sylvilagus* cf. *S. audubonii* or *S. floridanus* (or possibly some other rabbit-sized animal), two proximal tibia fragments, calcined, heat cracked and warped. Orientation uncertain. The specimen on the left has a transverse heat crack that does not show in this photo. N109 E96 (92.45-92.40 m), lot B-136.

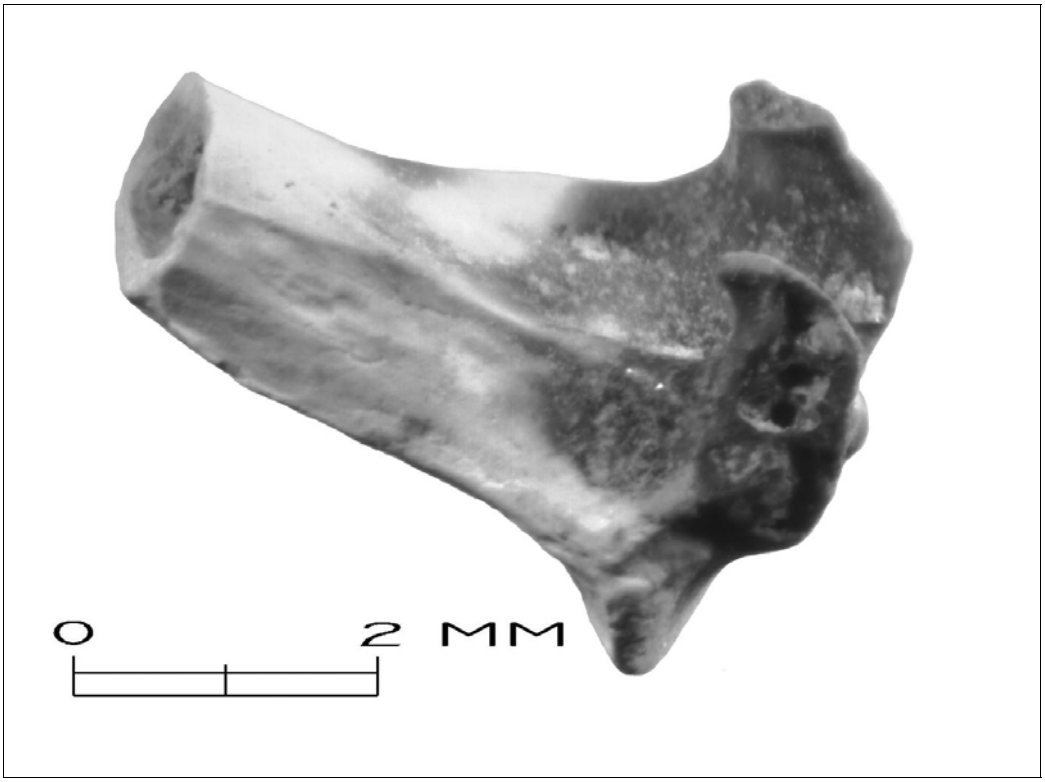


Figure 10.26. Calcined Fish Spine From the Ambient Fauna. Calcined base of dorsal fin spine (?) from unidentified small fish. N109 E96 (92.35-92.30 m), bulk matrix, coarse fraction. This fragment comes from one of the lots of bone not yet analyzed.

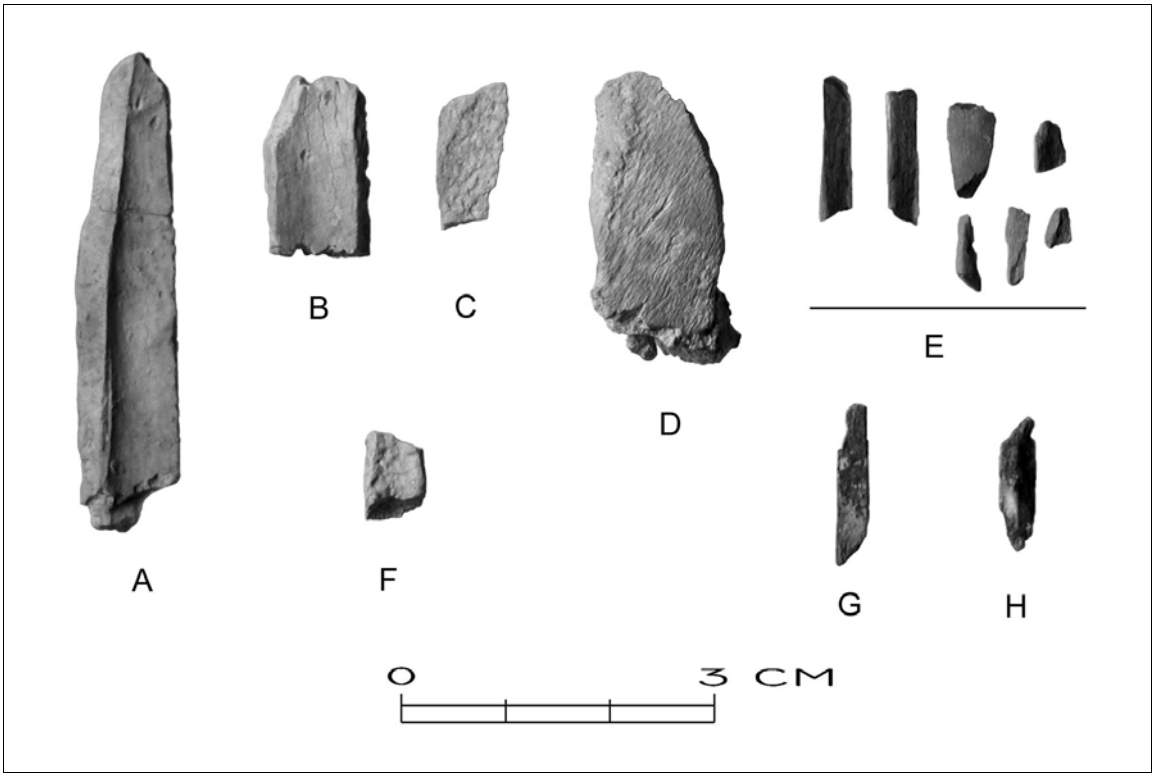


Figure 10.27. Ambient Bone and Antler From Large Animals. A, B, long bone shaft splinters, identical in appearance but not joining, deer-sized animal, N109 E103 (92.00-91.95 m), lot B-31; C, flat fragment with chemical dissolution (digestion?), D, possible rib fragment (?) from deer-sized animal, C-D are both from N110 E102 (93.08-92.90 m), lot B-33; E, seven small splinters of charred bone or antler, N110 E102 (92.20-92.15 m), lot B-54; F, long bone (?) fragment from deer-sized animal, N109 E96 (92.30-92.25 m), lot B-141; G, charred bone or antler splinter with manganese stains, N110 E102 (92.10-92.05 m), lot B-57; H, charred bone or antler splinter with manganese stains, N110 E102 (91.70-91.65 m), lot B-69.

Carapace Fragment From Extinct Large Tortoise (?)

A very distinctive small triangular bone fragment from the ambient bone assemblage is tentatively identified as a plastron or carapace fragment from *Gopherus hexagonatus*, an extinct large land tortoise. The fragment (Fig. 10.28) is 1.70 cm in maximum length, 1.28 cm in maximum width, and 5.4 mm in maximum thickness. The bone is beige (7.5YR 7.5/3.5), somewhat chalky and decollagenated in appearance. The exterior surface (Fig. 10.28, A) has a fine raised linear texture that is probably an adaptation for adhesion of the chitonous epidermal scutes. The opposite side exposes very large cells from the interior cancellous bone, and the interior surface of the fragment is missing, so the original thickness cannot be determined. One edge may correspond to part of a suture. The specimen was found in unit N109 E96 (92.25-92.20 m), lot B-142, in stratum 2A or at the contact with the overlying stratum 2B. The specimen is not mineralized and is similar to other beige, matte-textured bone from the deposits.

Although this specimen is quite small, the texturing of the exterior surface is very distinctive, and the coarse cellular structure on the opposite side even more so. Both the texturing and the very coarse cells match a *Gopherus hexagonatus* specimen from the Ingleside site in the Vertebrate Paleontology collections. No other taxa, either living or extinct, could be found in the collections matching this combination of characters. In particular, the large cellular structure rules out smaller kinds of turtles.

The chronology and paleoecology of *Gopherus hexagonatus* are poorly known. Rancholabrean specimens are known from the Beaumont Formation in Willacy County

(Westgate 1987), from the Ingleside fauna (Lundelius 1972), from Brooks County, the latter dated at 17,950 ± 70 RCYBP (C. R. Lewis, personal communication). Other specimens are also known from Briscoe County in the Texas Panhandle and from Kansas (Reynoso and Montellano-Ballesteros 2004). The genus appeared at least as early as the Miocene (Bramble 1982).

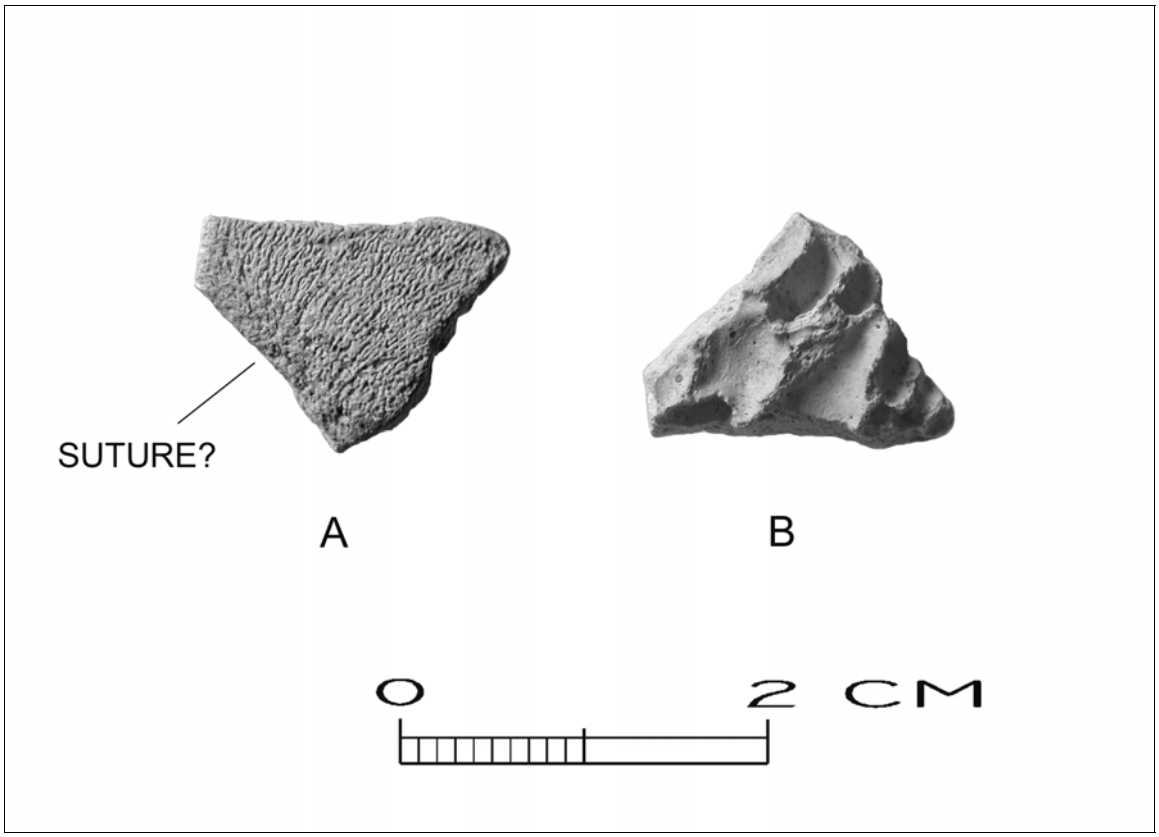


Figure 10.28. Carapace Fragment From Large Tortoise (?). Obverse and reverse views of small bone fragment from ambient bone assemblage, tentatively identified as extinct tortoise, *Gopherus hexagonatus*. A, exterior, surface with fine raised texture; B, exposed cancellous bone with very large cells on interior. N109 E96 (92.25-92.20 m), lot B-142, stratum 2A or contact with stratum 2B.

Another giant tortoise of Rancholabrean age, *Gopherus donlaloi*, has recently been described from northwestern Tamaulipas, but its geographic range is unknown (Reynoso and Montellano-Ballesteros 2004).

These Pleistocene giant tortoises were very large turtles. *Gopherus hexagonatus* had plastron lengths of 58-85 cm and carapace lengths of 59-64 cm (Westgate 1987:Table 28); *Gopherus donlaloi* has a recorded carapace length of 58 cm (Reynoso and Montellano-Ballesteros 2004:Table 3). *Geochelone wilsoni*, the other common extinct Rancholabrean turtle in south Texas, is considerably smaller. The contemporary equivalent of these tortoises is *Gopherus berlandieri*, the Texas Tortoise, a non-burrowing subtropical species no more than 22 cm long (Vermersch 1992:124-128) occasionally recovered from south Texas archeological sites (Shaffer 1989). The extinct varieties were burrowing tortoises, and the genus is characteristic of friable sandy soils (Bramble 1982:865). The Willacy County *G. hexagonatus* specimens were found in well-drained Rio Grande floodplain or levee deposits. In the Coleto Creek area, suitable substrates for burrowing could probably be found anywhere in the creek floodplain or sandy Miocene uplands. *G. hexagonatus* was formerly thought incapable of burrowing (Auffenberg 1962:32), but the position of the Willacy County specimens suggests they died in burrows, and the structure of the head and neck suggests an adaptation to digging (Bramble 1982). *Gopherus berlandieri* is markedly ectothermic (see Vermersch 1992:126) and it has been suggested that the giant extinct species were likewise, but capable of tolerating some climatic variation by burrowing (Westgate 1987:215). Reynoso and Montellano-Ballesteros (2004:835) suggest that these giant tortoises suffered extinction due to environmental desiccation and were replaced by *G. berlandieri* because it is better adapted to arid climates.

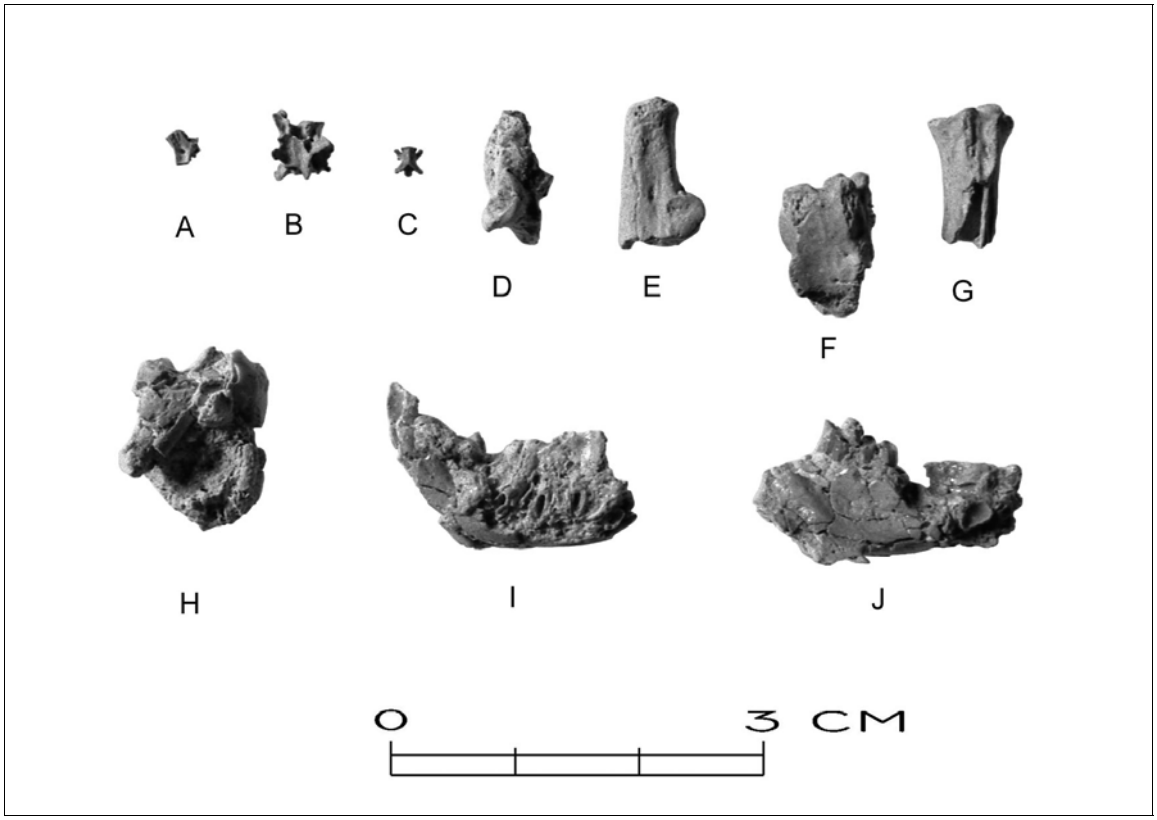


Figure 10.29. Ambient Bone, Various Lots and Taxa.

A, small salamander vertebra and B, larger salamander vertebra, both from N112 E97 (93.14-92.75 m, bag 1 of 2, lot B-111)
C, small snake vertebra, dorsal view, N110 E102 (92.45-92.40 m), lot B-46, from sediment sample
D, *Sylvilagus* sp. right distal astragalus from small rabbit, dorsal view, N110 E102 (91.90-91.85 m), lot B-63
E, *Sylvilagus* sp. proximal right calcaneum from small rabbit, lateral view, N110 E102 (92.10-92.05 m), lot B-57
F, centrum of caudal vertebra from raccoon-sized mammal, N112 E97 (92.25-92.20 m), lot B-123
G, very large frog, cf. *Rana catesbeiana*, proximal urostyle fragment, dorsal view, N109 E96 (92.50-92.45 m), lot B-135
H, *Procyon lotor?*, partial right M_1 in carbonate concretion, lateral view, N110 E102 (92.60-92.55 m), lot B-40
I, *Geomys* sp., left mandible, lateral view, N110 E102 (92.50-92.45 m), lot B-43, in carbonate concretion and fractured by carbonate growth
J, *Geomys* sp., right mandible with P_4, M_1 and M_2, medial view, N110 E102 (92.45-92.40 m), lot B-45

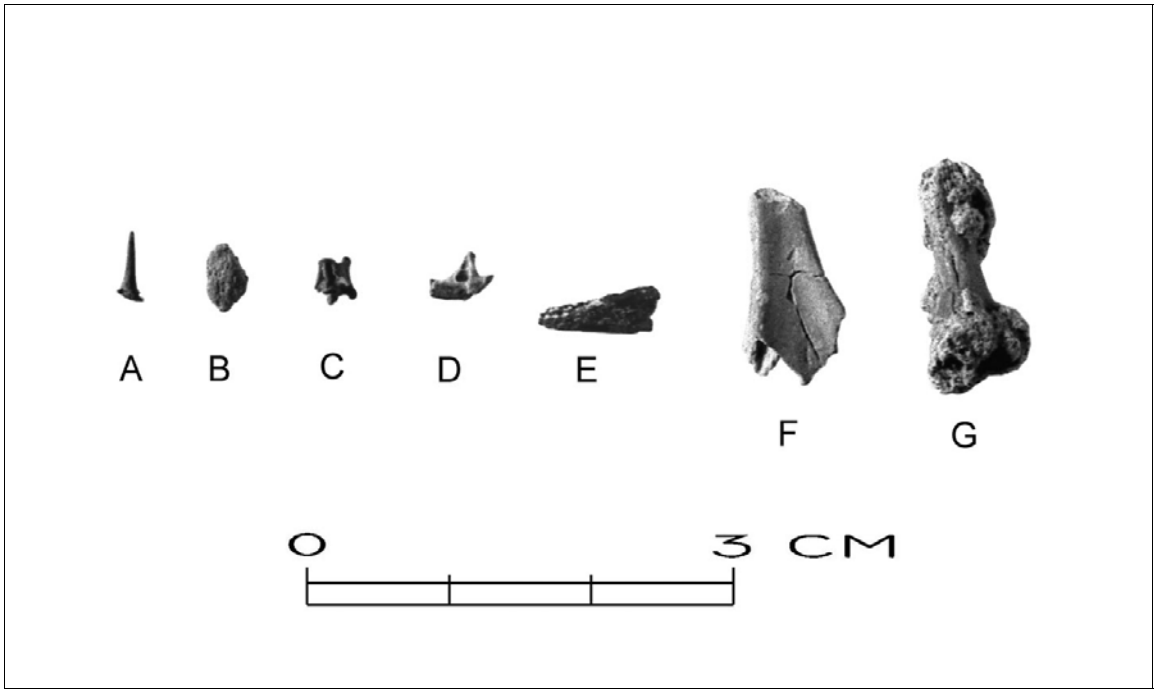


Figure 10.30. More Ambient Bone, Various Lots and Taxa.

A, unidentified fish tooth, orientation uncertain, and B, unidentified small mammal patella, posterior view, both N110 E102 (92.05-92.00 m), lot B-59
C, salamander vertebra, dorsal view, and D, *Cryptotis parva*, edentulous right posterior mandible fragment, medial view, both N109 E103 (93.14-92.90 m, sediment sample), lot B-2
E, unidentified small fish, left mandible fragment, dorsolateral view, N109 E96 (92.80-92.75 m), lot B-129
F, *Sylvilagus* sp., proximal scapula fragment, lateral view, and G, possible herpetofauna (?), distal humerus embedded in carbonate; both N109 E103 (92.80-92.75 m), lot B-7

The southeastern gopher tortoise, *Gopherus polyphemus*, is considered a keystone species because its remarkably long burrows provide habitat for many other species (Eubanks, Michener and Guyer 2003). Replacement of *G. hexagonatus* by *G. berlandieri* in south Texas presumably implies a significant reduction in burrow size, and this may have had cascading effects on other fossorial fauna at the end of the Pleistocene.

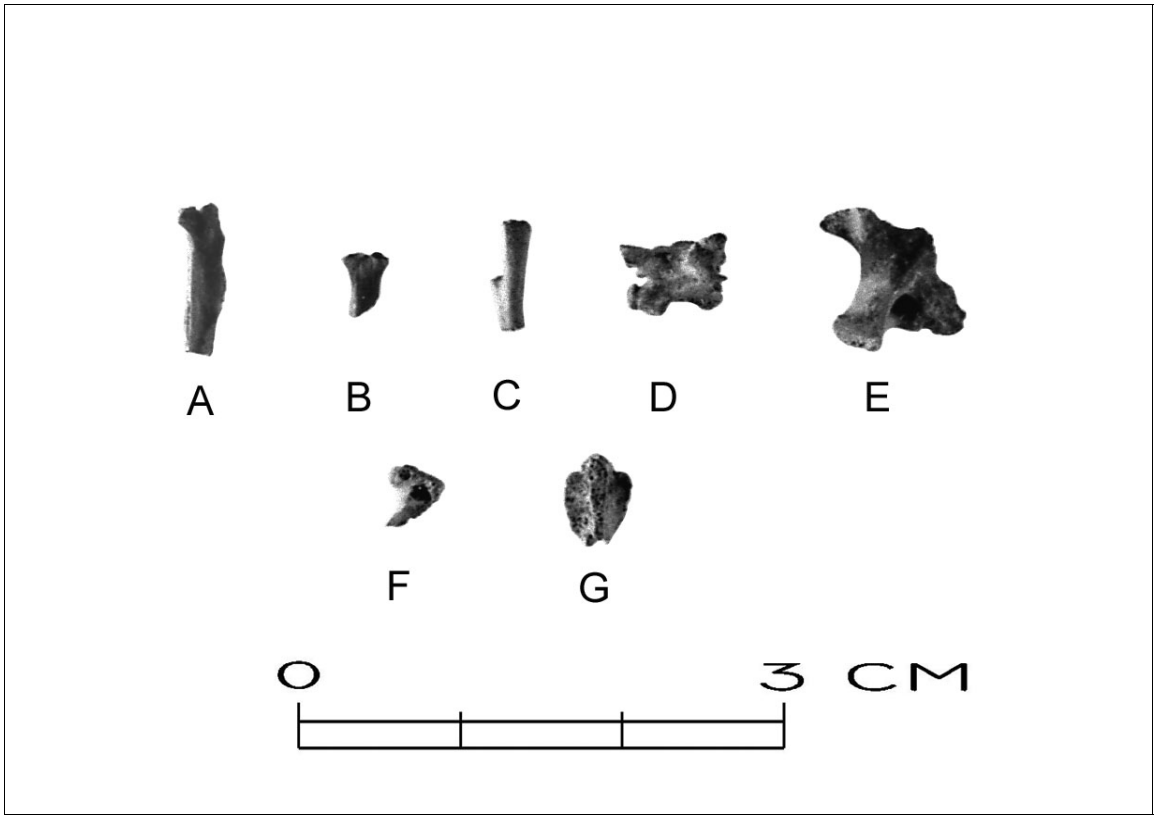


Figure 10.31. More Ambient Bone, Various Lots and Taxa.

A, unidentified *Chaetodipus*-sized rodent, proximal shaft of right femur (stained dark reddish-brown), medial view, N109 E103 (92.75-92.70 m sediment sample), lot B-9
B, cf. *Rana berlandieri*, urostyle fragment, ventral view, N109 E103 (92.45-92.40 m sediment sample), lot B-19
C, unidentified *Chaetodipus*-sized animal, left tibia shaft fragment, medial view, from Feature 7 fill, N109 E96 (92.30-92.25 m), lot B-141A
D, unidentified large snake vertebra, ventrolateral view, N109 E96 (92.70-92.65 m), lot B-131
E, *Scalopus aquaticus*, left distal humerus fragment (iron oxide stained), medial view, N109 E96 (92.60-92.55 m), lot B-133
F, unidentified small bird, left proximal femur fragment, anterior view, N112 E99 (92.50-92.45 m), lot B-92
G, cf. *Rana berlandieri*, pelvis fragment, posterior view, N109 E96 (92.45-92.40 m), lot B-136

Whittled Bone Pin (?)

This problematical item (Figs. 10.32, 10.33) is a small, tapering pin made of bone (or possibly antler) recovered from N109 E96 (92.20-92.15 m), lot B-144 m. It is distinctly tabular in cross-section, and when viewed on edge, appears somewhat laminated. The tabular shape and faint laminations suggest it is bone. It was compared under magnification to recent samples of bone and antler, and a sample of fossil mammoth ivory. The surface texture also corresponds fairly well to antler, but not to ivory. The object was broken during excavation, providing an opportunity to inspect a fresh cross-section. In section, the interior is laminated and darker yellowish in color, haloed by a lighter cream-colored zone (diagenesis after manufacture?).

The overall shape is irregularly tapering with heavily rounded edges, a rounded tip, and heavily polished surfaces with occasional small carbonate deposits. The length is 1.65 cm, maximum width 4.7 mm, and maximum thickness 2.4 mm. Because of the heavy rounding and polishing, it resembles a digested bone fragment with extensive gastric polish, but there are faint striations on the flat surfaces that may be whittling marks, and these suggest it is actually an artifact rather than digested bone. Most of the striations are parallel to the long axis, but some deviate at slight angles.

This item is tentatively interpreted as a bone artifact rather than digested bone, and if the identification is correct, it is the only bone artifact known from the bench deposits. Its function is unknown.

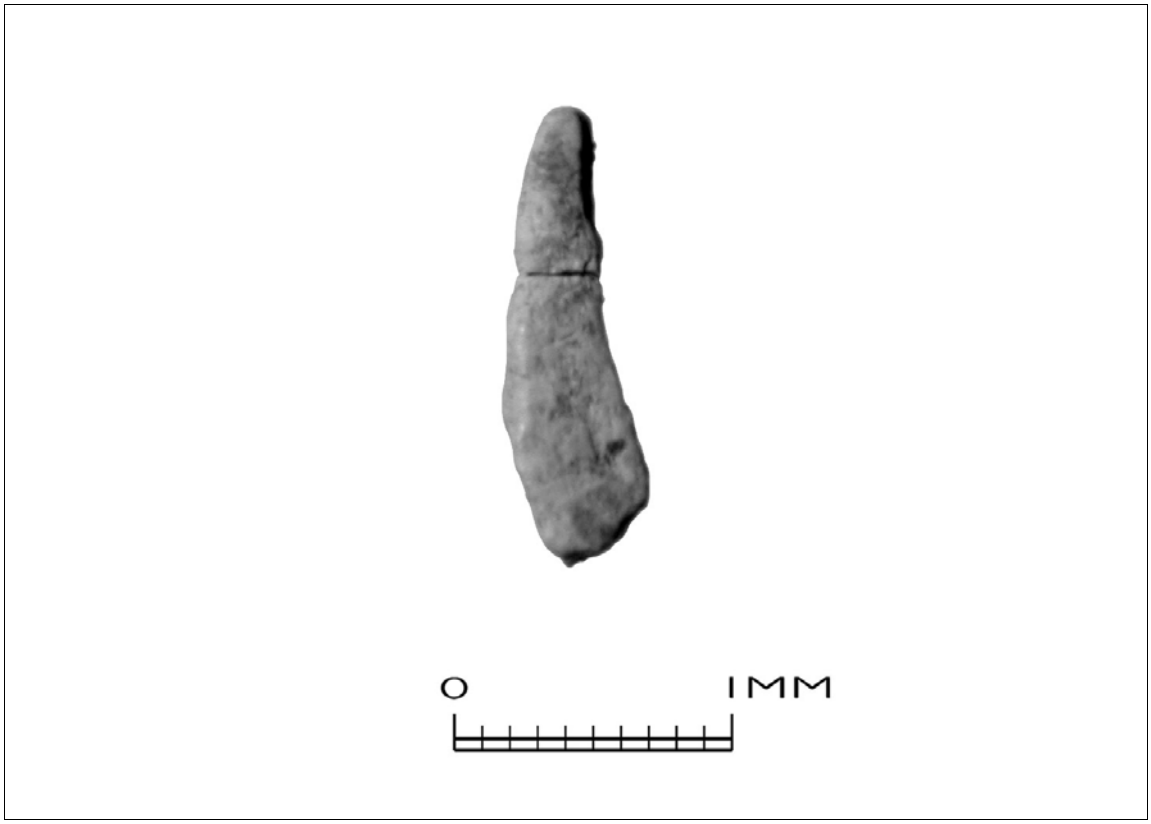


Figure 10.32. Whittled Bone (?) Pin. Whittled and polished tabular bone (?) or antler pin from N109 E96 (92.20-92.15 m), lot B-144. Break is excavation damage.

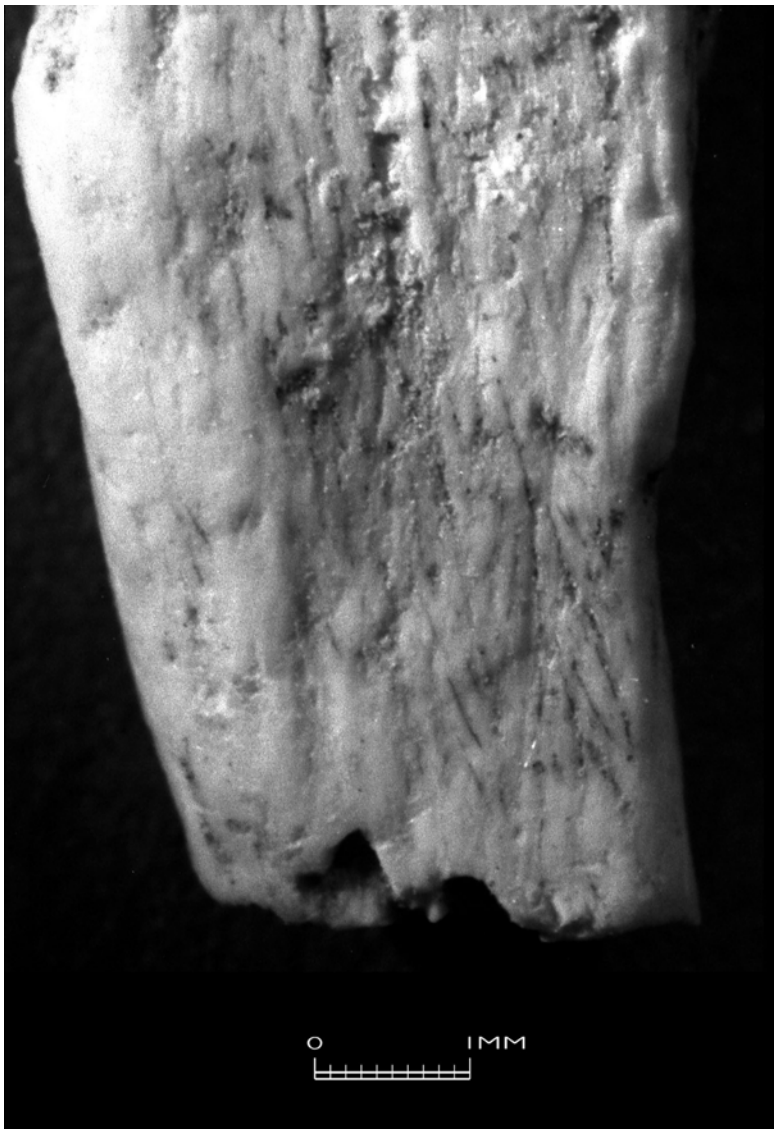


Figure 10.33. Detail of Whittled Bone (?) Pin. Magnified view of recently broken end of tabular pin, showing surface texture, rounding and polishing, and small carbonate deposits.

THE HEARTH DEPOSIT

The hearth deposit is a microvertebrate bone bed similar to the hearth-proximate bone concentrations found at the Aubrey site (Ferring 2001:189) and possibly to the Rodent Level Faunule at the Medicine Lodge Creek site, Wyoming (Walker 1975). Table 10.17 lists counts for the identified portion of the hearth deposit. Not included is a large bone lot (B-107A) that has been informally inspected but not yet identified. Figures 10.6 and 10.7 show the composition of the assemblage by NISP, both with and without categories of unidentified specimens. Figure 10.34 shows the composition by MNI. Since the hearth deposit is believed to be essentially a single relatively short-term depositional event, all of the identified lots are aggregated to compile this simplified diagram.

Figure 10.34 was compiled with the application of considerable simplification and many assumptions. Consider the total for salamanders. All of the salamander material is likely *Ambystoma texanum*, but some is identified as *Ambystoma* sp. and some only as unidentified or possible salamander. The material consists of vertebrae, humerus and femur fragments, ilia, and unidentified long bone fragments. Three proximal humerus fragments suggest a minimum of three individuals, but there are at least 29 unidentified long bone fragments. There are about 108 vertebrae. Since Ambystomatid salamanders have about 42 vertebrae per individual (15 trunk, 1 sacral, 3 caudosacral, and about 33 caudal; Babcock and Blais 2001), about two and a half individuals would account for the vertebral total (not including additional specimens in lot B-107A). Francis (2002:16) lists an average of about 40 vertebrae for salamanders in general. However, terrestrial salamanders (like lizards) may practice tail autotomy (Pfingsten and Downs 1989:7), so the 108 vertebrae could conceivably account for more than three individuals, if any of

them had lost tails. Nevertheless, three seems the most plausible estimate for the identified portion of the assemblage, so that number is used as a minimum estimate.

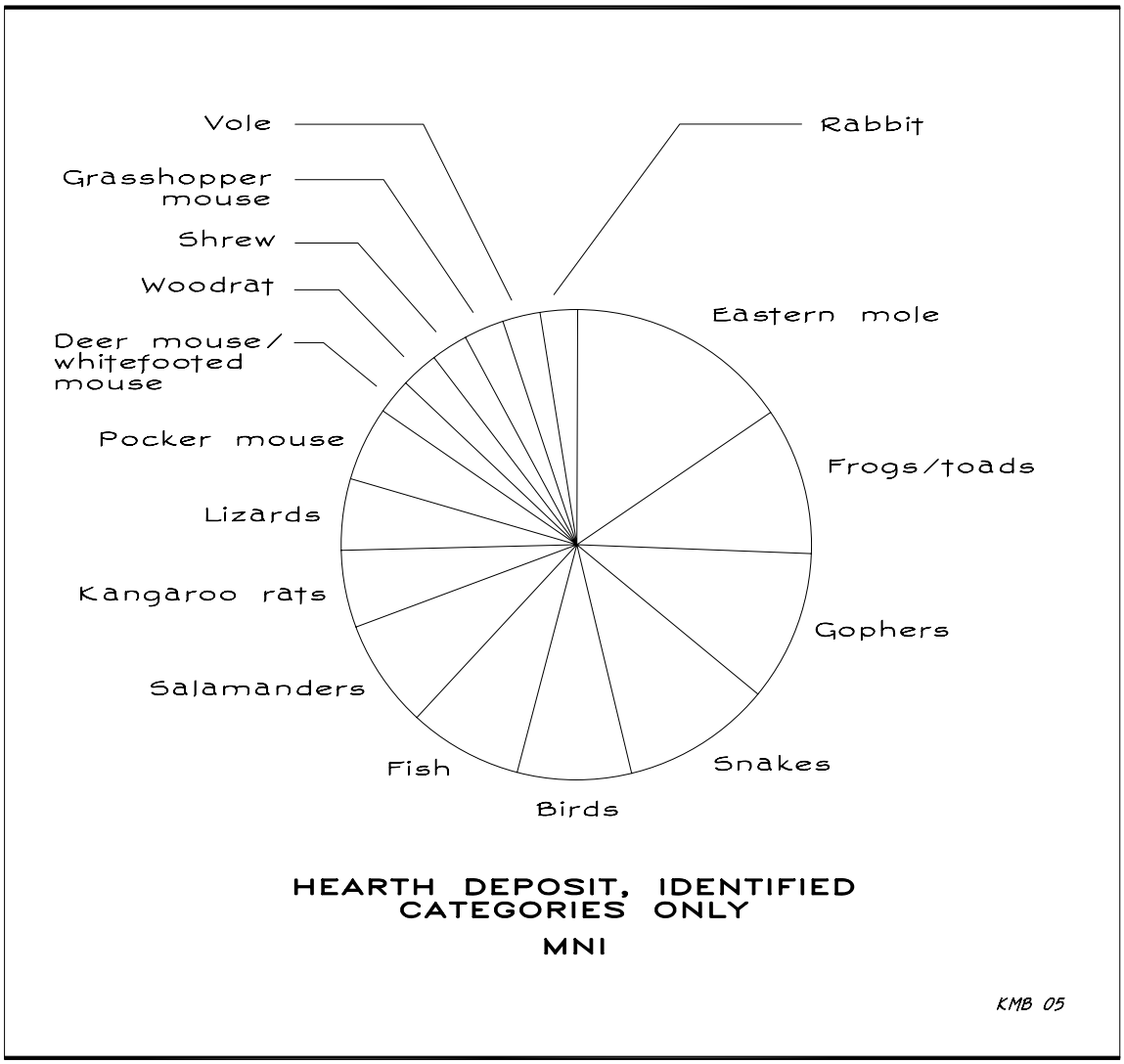


Figure 10.34. Hearth Deposit, Taxonomic Composition by Minimum Number of Individuals. Relative proportions of major vertebrate categories are ranked by MNI. All of the analyzed lots from the hearth deposit are aggregated here. Compare with Figure 10.24.

Figure 10.34, like Figure 10.24, should be viewed with a dash of skepticism because of the many unknowns involved in compiling a list of minimum numbers. It should also be kept in mind that there are over 2400 unidentified fragments in the analyzed part of the assemblage – fragments that, could they be identified, might change the picture significantly – and even more in the unanalyzed part. In terms of composition, the hearth deposit is similar to the ambient fauna, differing in these respects:

1) No remains of turtles, raccoons, or large animals are known from the hearth deposit (charred splinters of deer bone are entirely absent) and there are no extinct taxa

2) No recognizable evidence of gar, cotton rat or jackrabbit was found among the fish, rodent and lagomorph remains from the hearth deposit

3) *Peromyscus* sp. (deer mouse or whitefooted mouse) is present in the hearth deposit

4) The sample size is larger than the ambient assemblage, so it is not surprising that a somewhat larger variety of snakes, frogs and toads could be identified

5) Rabbits and gophers are noticeably less abundant than in the ambient faunal assemblage

As in the ambient fauna, there is a heavy representation of non-mammals from riparian habitats and mammals from upland habitats, with the riparian animals roughly twice as abundant as the upland animals, whether measured by NISP or MNI. Some of the snakes are identifiable as probable floodplain or wetland species. Perhaps roughly 60% of the MNI values represent riparian taxa, another 20% are perhaps upland taxa, and another 20% are of unknown derivation (birds, for example, could have been obtained either in upland or riparian habitats).

Table 10.17. Hearth Deposit: Measures of Abundance.

	NISP	MNI
Fish, unidentified	49	3
Snakes		
cf. *Rhinocheilus lecontei*	1	1
cf. *Diadophis punctatus*	4	1
Colubrinae	8	2
Storeria dekayi or *Virginia striatula*	3	1
Viperidae	2	1
Snake, unidentified	9	1
Snake or lizard	3	N/A
Lizards		
cf. *Sceloporus* subadult?	1	1
Lizards, unidentified	10	1
Birds, unidentified	18	3 ?
Amphibians		
cf. *Bufo* sp.	1	N/A
Bufo cf. *B. americanus*	1	1
Hylidae or Microhylidae	2	1
cf. *Rana berlandieri*	6	2
Frog/toad, unidentified	15	3 ?
Salamanders		
Ambystoma texanum	63	3 ?
cf. *Ambystoma* sp.	54	2 ?
Salamander, unidentified	35	N/A
Amphibian, unidentified	13	N/A
Mammals		
Cryptotis parva	1	1
Soricidae	1	N/A
Scalopus aquaticus	86	6
Geomys sp.	21	4 ?
cf. *Dipodomys ordii* or *D. compactus*	5	2 ?
Chaetodipus hispidus	17	2 ?
Chaetodipus/Perognathus sp.	1	N/A
Heteromyidae	2	N/A
Onychomys leucogaster	3	1
Peromyscus sp.	1	1
Neotoma sp.	37	1
P. pinetorum or *M. ochrogaster*	5	1
cf. *Sylvilagus audubonii* or *S. floridanus*	2	1

(Table continued on next page)

(Table 10.17 continued from previous page)

	NISP	MNI
Insectivore, unidentified	1	N/A
Rodent, unidentified	46	N/A
Small mammal, unidentified	159	N/A
Mammal, unidentified	100	N/A
Animal, unidentified	2123	N/A
TOTALS:	2910	47

Heat-Altered Bone From the Hearth Deposit

There are only seven specimens with evidence of heat alteration in the analyzed portion of the hearth deposit. Unidentified animals and smallmouth salamander are represented. Although the hearth and the adjacent microvertebrate bone bed are closely associated in three-dimensional space, there is no indication the bone itself was "roasted" in the Feature 5 fire. The animals may have been cooked, but they may have been cooked in some other fire, elsewhere, or the cooking process may not have affected the bone enough to leave macroscopic visual evidence. Only one fragment was found in Unit 2; the rest were all found in N113 E98.

These heat–altered items might represent animals that were roasted somewhere, then eaten and deposited in a latrine area next to the hearth, or they might represent bone fragments already present in the sediments and fortuitously exposed to heat when the Feature 5 fire was built. There is no way to discern the correct sequence of events. The fragment found in Unit 2 is calcined, and calcining requires direct exposure to fire and high temperatures; bone buried more than 5 cm below a fire will only be charred, not calcined (Stiner *et al*. 1995:230-231; Bennett 1999). Temperatures somewhere in the

general range of 600-900° C are required for calcining (Shipman, Foster and Schoeninger 1984:313). A distal *Sylvilagus* sp. femur fragment found about 10 cm below Feature 5 when it was removed showed no evidence of heat alteration.

The following heat-altered items were found:

Lot B-149, Unit 2, fired surface of Feature 5 and adjacent area. Calcined V-shaped bone fragment. Judging by size and thickness, it may be from a lagomorph-sized or larger animal, though not necessarily a mammal. The fragment is white to light blueish-white (7.5YR 7.7/0) to light gray-brown (7.5YR 7/2) with a somewhat glossy texture on the exterior, black on the interior, possibly corresponding to Stage IV (645-<940° C) of Shipman, Foster and Schoeninger 1984:313). It measures 6.1 mm long, 3.45 mm wide, with a wall thickness of 0.25 to 1.05 mm (Fig. 10.38, G).

Lot B-106, N113 E98 (92.443-92.400 m). *Ambystoma* cf. *A. texanum*, three heat-darkened salamander vertebrae. One is nearly complete, another slightly less so, the third partial. Two have recent cracks, probably because heating made the bone brittle. All are a deep glossy brown (2.5YR 2.5/2.5 to 2.5YR 3/3.5) and yellow. They are not charred or carbonized, but rather have a carmelized appearance (Fig. 10.49, C).

Ambystoma texanum, one heat-altered ilium (Fig. 10.35, A). This specimen is dark brown (2.5YR 2.7/2) and has the same glossy carmelized appearance as the vertebrae described above, and may be part of the same individual. Specimen is 2.2 mm long and 1.8 mm wide.

Unidentified animal, two very small bits of brown, carmelized-appearing bone similar to those above, and possibly part of the same salamander. One resembles a semispherical ball joint, is 1.4 mm in diameter and extensively cracked; the other is a small bit of cancellous bone 1.3 mm across.

Archeologists commonly expect visual proof in the form of cutmarks or burning as evidence that animals were consumed by hunter-gatherers, but most archeologists are focused heavily on large animals like deer and bison. The ethnographic and archeological record shows that small animals were treated differently, and cutmarks and burning

cannot often be expected for small animals that may have been roasted whole, dismembered by tearing, or pounded into mush with a hammerstone and anvil.

In rare cases, high rates of burning may be seen on rodent remains (23% of individuals reported by Simonetti and Cornejo 1991), but a more typical example is the archeological record from the Henderson site, a Late Prehistoric horticultural pueblo in New Mexico. There, Speth (2000:96) estimates the following frequencies for burned bone:

bison	~6.0% burned
jackrabbit	~2.5% burned
cottontail	~2.0% burned
prairie dog	~2.0% burned
gopher	~0.8% burned
small rodents	~0.6% burned

Speth makes a convincing case that at least the first five categories are food remains, yet all show low rates of heat alteration. Cutmarks are not often found on the remains of woodrat-sized or smaller animals, and the occasional cases seen (Parmalee 1975; Young 1980:105) are probably an indication that the animal was skinned rather than singed before cooking.

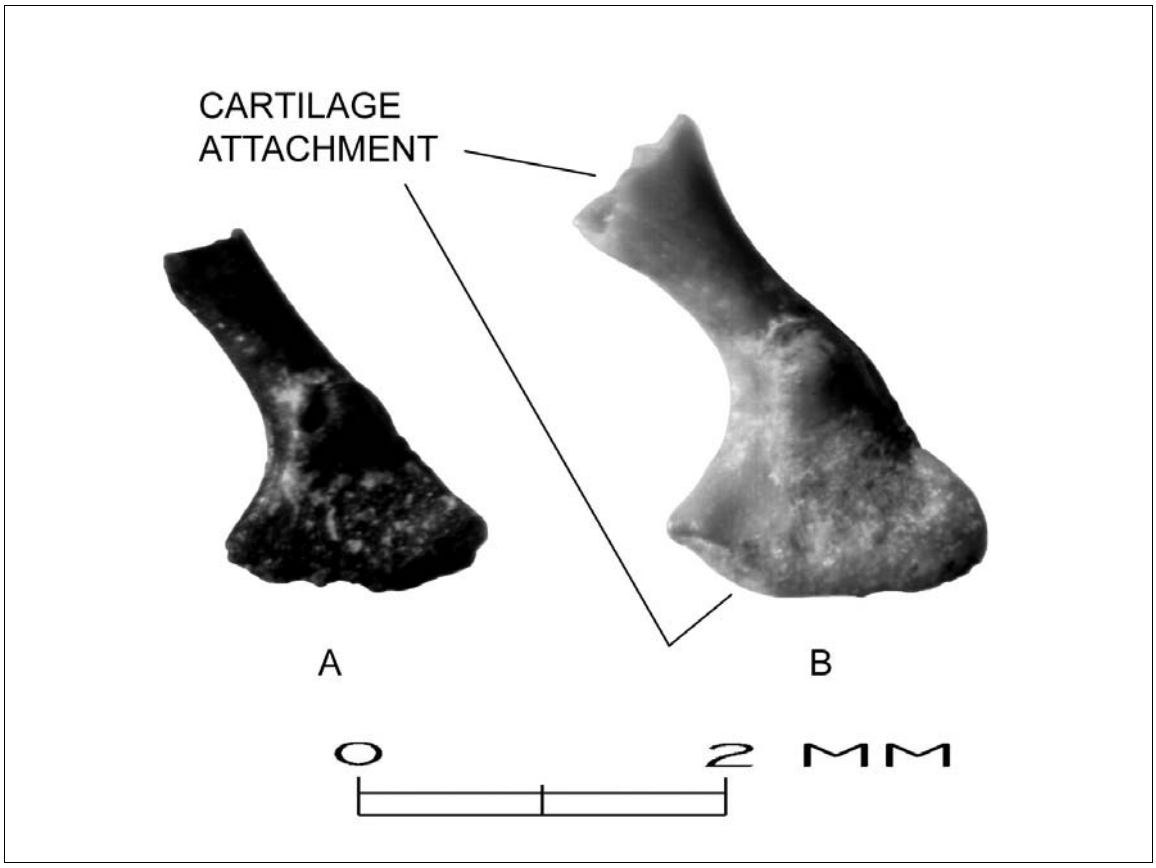


Figure 10.35. Smallmouth Salamander Ilia From the Hearth Deposit. Two ilia of *Ambystoma texanum*. Specimen A is charred. The ends are irregular because cartilaginous extensions are attached here. N113 E98 (92.443-92.400 m), lot B-106.

Preparation of Small Animals for Human Consumption

Although North American ethnographers have seldom bothered to record native uses of small animals with any detail or consistency, enough information remains to

establish a few points. One early account comes from Sonora, where Pfefferkorn recounts:

> The hungry Sonoran eats not only rats, but also snakes, lizards, locusts, worms, caterpillars, and all kinds of insects. He cuts off the head and tail of a snake, throws the body into the fire or upon hot coals, and after it has been half roasted he removes it, beats off what ashes may be clinging to it, and devours it whole. He does the same with lizards….
>
> The Sonoran does not boil meat; that would be too much ceremony for him. It is enough for him if his meat is partly roasted. A thin, pointed piece of wood does him for a spit. On this he sticks the meat, holds it in the flame, turns it around often so that the fire can get at it on all sides, and after it has sputtered awhile in the fire, it is roasted enough to please him…
>
> Rats are put on spits as are larks in Germany and are roasted like other kinds of meat. They are not disemboweled (Pfefferkorn 1949:199; translation of original 1794 edition).

One of the earliest accounts of small mammal processing in the western U.S. is by Captain J. H. Simpson (1876:53), who records a visit to the Gosiute Indians on May 9, 1859:

> While this was going on, an Indian came in from his day's hunt. His largest game was the rat, of which he had a number stuck around under the string of his waist. These were soon put by the old woman on the fire, and the hair scorched; this done, she rubbed off the crisped hair with a pine-knot, and then, pressing her finger into the paunch of the animal, pulled out the entrails. From these, pressing out the offal, she threw the animal, entrails and all, into the pot (Simpson 1876:53).

Among the Wintu

> Small game was generally cooked in the following manner. It was singed, the paws and tail were cut off, and the entrails removed. The animal was then roasted in a bed of hot coals. Then the hide might or might not be removed. The body was

> then pounded, bones and all, until it was fine and crumbly. Sometimes the pounding was done before roasting (DuBois 1935:14).

Edward Palmer, describing the Paiute of the 1860s-1870s, remarked

> I saw them collect grasshoppers, land turtles, lizards, snakes, mice, ratts and rabbits, swifts and horned toned [*sic*, toads] and without taking off their hides or extracting their entrals threw them on the fire cooked them a little, with their fingers took them out and devoured them… (Heizer 1954:7).

Among the Walapai,

> Rats are boiled unskinned and ungutted. Some eat them whole; but some throw away the skin and viscera. For roasting, rats are skinned, but not gutted. The carcasses are tied together, belly to belly and head to rear, lashed with yucca in pairs. After the leg bones are broken and the legs twisted together, the bundle is thrown into the fire and rolled over until browned on all side. The rats were then ready for storage and could be preserved for several months… When rats are boiled the guts are taken out … They are not skinned but eaten right out of the skin. The guts are given to old people who roast them over hot coals. Rats are also roasted. The "big guts" are taken out and thrown away; the small guts are left in. Six or seven are roasted together in the earth oven. Mice are killed and eaten like rats. It takes a good many of them to make a meal. They are roasted whole. The kangaroo rat is cooked in the earth oven, neither skinned nor gutted. The pine squirrel… is roasted whole on coals. The tail is cut off… The ground squirrel… roasted in the earth oven after the "big guts" are removed. Chipmunks… are roasted whole on coals. The prairie dog… is skinned and roasted. The viscera are left in and eaten…. The gopher… is roasted and eaten; the skin is not removed. Small birds were cooked whole. Some birds had the beak and legs cut off before roasting. [Chuckwalla:] The viscera are removed and thrown away. Everything else is eaten. The chuckwalla is roasted in the pa'vuk. The tail is put in the mouth, and the back broken so that a circle can be made with the legs inside. After roasting, the animal is cut up (Mook 1935:75-76).

At Portales Cave, Tamaulipas, in archeological deposits ca. 5650 RCYBP, Marsh (1964:54) found a nearly complete skeleton of a pocket mouse (*Perognathus* sp.) in one

coprolite; one side was charred black, the other side less so. In another coprolite, a large part of a Northern pygmy mouse (*Baiomys taylori*) skeleton was found, with the extremities of the legs and the lower part of the jaw charred. These are probably examples of animals that were overcooked and passed intact through the digestive tract as a result. Charred lizard (leg bones), unidentified rabbit-sized mammal (patella) and small rodent (leg bones) remains, as well as the charred ribs and vertebrae of a snake were also found.

Table 10.18 presents a small sample of some ethnographic records. Animals smaller than lagomorphs were almost always roasted or boiled whole. Boiling was most common for cultures with ceramics, but most hunter-gatherers were probably familiar with stone boiling in perishable containers (there is no evidence of stone boiling in the bench deposits, nor were local stones very suitable for it). Boiling would not leave any obvious evidence of heat alteration. Low levels of heating could possibly be detected with transmission electron microscopy (Koon, Nicholson and Collins 2003), but only if collagen can be extracted from the bone, and it is also known that long-term diagenesis duplicates many of the physical effects of boiling (Roberts *et al*. 2002). In cases where small animals are roasted, either on spits or in coals, scorching of caudal and foot elements might be expected, but the other skeletal elements would be shielded from scorching by meat (Shipman, Foster and Schoeninger 1984:322; Morlan 1994:139). In cases where the entire animal is pounded into flour, the bones are simply removed from the archeological record. In the bench deposits, there are many bones and no evidence of ground stone tools (cf. Yohe, Newman and Schneider 1991), so pulverization of small animals can probably be ruled out.

Processing of a woodrat is described by a Kiliwa informant from Baja California as follows:

> First a fire is built of small branches. While the flames are high the whole animal is tossed into the fire. When the hair is well singed the rat is removed with a pair of sticks, used as tongs, and placed on a branch of fresh juniper or some similar evergreen. The skin, partially cooked, slips off cleanly and easily. The entrails are removed and the rat laid on the green boughs. After the flames of the fire have died down sufficiently the carcass is placed on the coals to roast for 10 or 15 minutes.
>
> The most remarkable part of the procedure takes place after the meat is cooked. The legs are pulled off and nibbled in the classic manner. However, the rib cage, spine and pelvis are placed on a flat rock, sometimes a metate, and thoroughly crushed with a hammerstone. The carcass, well shredded, is then eaten, bones and all (Michelsen 1967:76).

In this case, only the axial skeleton is selectively removed from the archeological record, while in others the entire animal is pulverized, but it is clear that animals are not always pulverized, for many of the coprolites analyzed in the Borderlands region contain small bones that have been masticated but not powdered.

Lagomorphs may either be treated like the smaller animals or more like large animals. They may be dismembered before cooking and the long bones may be broken to extract the marrow or cut for bead manufacture (Lubinski 2003). In cases where rabbits are roasted whole, scorching may be confined to foot elements (Hockett and Bicho 2000:719), but in other cases long bones may be extensively burned (Lubinski 2003:201). Rabbit-roasting pits have been recognized archeologically in New Mexico (Skelton 1981:63), marked by concentrated bone fragments, many charred.

I suggest this evidence indicates that the absence of cutmarks and the very low incidence of charring in bone from the hearth deposit cannot be taken as any kind of proof that the animals were not cooked. For small animals, evidence of cooking may often be too subtle to be detected by visual inspection.

Juveniles

As in the ambient fauna, there are few juveniles present in the hearth deposit. The material includes a rabbit, a woodrat, a kangaroo rat, possibly gopher and lizard, and some unidentified material that could either belong to these individuals or some other unrecognized animal. The following items were recovered:

Lot B-149, Unit 2, Feature 5 and adjacent area
Sylvilagus cf. *S. audubonii* or *S. floridanus* (Desert or Eastern cottontail rabbit), left calcaneum with epiphysis unfused, from young adult; Fig. 10.38, C

Lot B-105, Group 2, N113 E98 (92.50-92.40 m)
Heteromyidae (unidentified pocket mouse or kangaroo rat), left proximal tibia without epiphyses, from juvenile, about 30% complete (possibly part of the *Dipodomys* individual listed below?); Fig. 10.42, B

Group 1f, *Geomys* sp. (pocket gopher), proximal shaft fragment of right femur comparable in size to subadult *G. bursarius*, 30% complete

Lot B-106, N113 E98 (92.443-92.400 m)
Neotoma sp. (unspecified woodrat), shaft of right femur, missing distal epiphysis, from young adult, about 80% complete

Unidentified rodent, one left proximal femur of juvenile; one proximal epiphysis from juvenile, complete except for some exposure of cancellous interior

Unidentified small mammal, fragment of proximal radius from juvenile; Fig. 10.43, I

Unidentified lizard, one vertebra from a small lizard, perhaps subadult *Sceloperus* sp.

Lot B-107, N113 E98 (92.40-92.30 m), *Dipodomys* cf. *D. compactus* or *D. ordii* (Gulf coast or Ord's kangaroo rat), one deciduous right P_4

The scarcity of juveniles in the hearth deposit raises the question of season of capture. The ethnographic record is almost nonexistent. The Wintu were said to hunt woodrats in the winter when they were sluggish (Lapena 1978:337), but the Eastern Pomo hunted them year-round (McLendon 1977:12). Life history data for these genera are no more helpful. All of these animals – rabbits, woodrats, and kangaroo rats – are probably polyestrous and breed nearly year-round in south Texas. According to Schmidly (2004:462), for the Desert Cottontail "in Texas, onset of breeding begins in February, and pregnant females, lactating females, and young in the nest have been found in every month except January, July, and October. There may be two or more litters a year." For the Eastern Cottontail, the breeding season extends from January to September, but the peak is in February-March, with a gestation period of about 40 days (Schmidly 2004:461; see also Chapman and Morgan 1974; Conaway, Sadler and Hazelwood 1974). I have no data for fusion rates of the calcaneum in *Sylvilagus*, but Bothma, Teer and Gates (1972:1219) documented fusion rates for the humerus of *Sylvilagus floridanus* at Welder Wildlife Refuge and found the proximal epiphysis requires at least 10 months to fuse in most individuals (range, 7-14 months). The variability in breeding dates plus variability in fusion rates, when added together, are so extensive that a juvenile rabbit with an unfused calcaneum could have been collected any time of the year.

For the Eastern Woodrat, the breeding season is the same as the Eastern Cottontail, January to September (with a gestation period of 33 days; Schmidly 2004:431). However, in south Texas, Southern Plains woodrats are said to be polyestrous, breeding throughout the year and producing up to 5 litters per year (Raun 1966:14; Merkelz and Kerr 2002:74-75; Suchecki *et al*. 2004; see also Conditt and Ribble 1997), although there may be peaks in reproduction in February-April and November-December

(Raun 1966:14; Johnson 1952:101). It also seems likely that in the equable climates of the Younger Dryas, breeding season for most animals were longer, and some animals that are monestrous now may have been polyestrous during the Pleistocene. This is suggested in part by the fact that for all these animals, breeding season becomes longer with decreasing latitude.

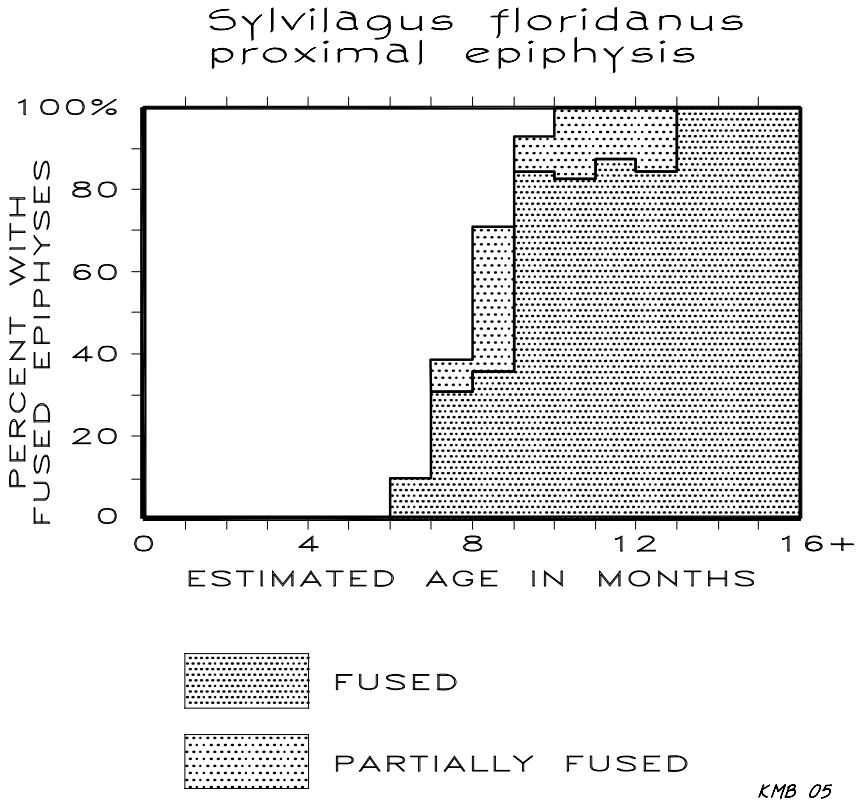


Figure 10.36. Eastern Cottontail, Fusion Rates for Proximal Humerus. The rate of fusion for the proximal epiphysis of the humerus is shown here for *Sylvilagus floridanus* in San Patrico County (adapted from Bothma, Teer and Gates 1972:Fig. 2). The fusion rate for the calcaneum is assumed to be roughly comparable.

In summary, identifying the few juveniles in the hearth deposit offers no help for recognizing in which part of the year the deposit was created. Of far more interest is the question of why so few juveniles seem to be present in the sample of predated individuals in the first place. The poorly ossified bones of juveniles might have been removed by chemical dissolution (dissolution either by stomach acids of predators or by groundwater after burial), but a more promising answer is found in Gerald Raun's study of Southern Plains woodrats in San Patricio County. Raun (1966:Table 12) found that adults represented about 86% of his year-round trapped sample of woodrats (range, 71-96%), and he attributed it to nonseasonal breeding and small litter size. This is probably the explanation for the scarcity of juveniles in the bench deposits. If many of the species were polyestrous, producing small litters, there may have been few juveniles in the population, especially when pre-Holocene climatic conditions prevailed.

It should be observed that some of the species present in the bench deposit (most notably cotton rats and voles) are notorious for cyclic population sizes, but no juveniles of these "unstable" taxa were found.

Table 10.18. Ethnographic Examples of Small Animal Preparation.

Prey taxon	Affiliation	Treatment	Reference
Peromyscus/ Reithrodontomys	Northern Paiute	roasted in coals	Fowler 1989:24
unspecified mice	Northern Ute	cooked in hot coals, then skinned, entrails removed	Smith 1974:49
unspecified mice	Digueno	roasted or pounded and stewed	Cuero 1970:32-33
kangaroo rat	Northern Paiute	roasted in coals	Fowler 1989:24
kangaroo rat	Seri	boiled with salt	Malkin 1962:9
unspecified rats	Northern Ute	entrails removed, then roasted in coals	Smith 1974:49
unspecified rats	Digueno	roasted or pounded and stewed	Cuero 1970:32-33
unspecified rats (woodrat?)	Southern Paiute	baked in ashes unskinned; sometimes skinned and eviscerated, never boiled	Kelly 1964:52
unspecified rats (woodrat?)	Yavapai and Tulkepaia	make incision in abdomen and roast; or skin and boil	Corbusier 1886: 328
unspecified rodents	Tepehuan	skinned, eviscerated, roasted on spit or in coals	Pennington 1969: 125
rats, mice, quail, ground squirrels	Luiseño	broiled on coals	Sparkman 1908: 199
woodrat, mice, groundhog, ground squirrel, gopher, chipmunk	Owens Valley Paiute	eviscerated, skin sewn up with stick, roasted buried in coals	Steward 1933:255
woodrat	Northern Paiute	singed, roasted in coals	Fowler 1989:24
woodrat	Navaho	clean without removing fur, salt, bake in coals	Bailey 1940:284
woodrat	Havasupai	pit-baked, covered with moist sand	Weber and Seaman 1985:63
woodrat	Western Apache	roasted on hot coals and ashes, made into soup; boiled rats mashed except for head and vertebrae; or singed whole in the fire and fur scraped off with a stick, eviscerated	Buskirk 1986:136
woodrat	Zia Pueblo	skinned and cooked in grease	Stevenson 1894: 26
woodrat	Seri	skinned and roasted in the ground under coals	Felger and Moser 1991:53

(Table continued on next page)

(Table 10.18, continued from previous page)

Prey taxon	Affiliation	Treatment	Reference
woodrat	Yaqui	cooked in olla	Moisés, Kelley and Holden 1971:180
gopher	Maya	singed in pit oven, fur scraped off, rinsed, placed on coals and covered with hot rocks, leaves and dirt; then eviscerated; meat is pulled off bones; skin eaten; vertebrae and long bones given to dogs	Hovey and Rissolo 1999: 273-274
gopher	Tepehuan	skinned, eviscerated, roasted on spit or boiled with other kinds of meat	Pennington 1969:124-125
mole	Pima Bajo	skinned, eviscerated, roasted on a spit	Pennington 1980:201-202
mole	Tepehuan	skinned, eviscerated, roasted on spit or boiled with other kinds of meat	Pennington 1969:124-125
chipmunk	Southern Paiute	roasted in ashes	Kelly 1964:52
chipmunk	N. Paiute	roasted in coals	Fowler 1989:24
chipmunk	Tarahumara	roasted on spit without skinning or eviscerating	Bennett and Zingg 1935:118
ground squirrel	Northern Paiute	fur singed, removed with grass brush, entrails evacuated then replaced, body pinned shut, body roasted entire; sometimes roasted without cleaning or dressing; brains sucked from skull	Wheat 1967:9
ground squirrel	Northern Paiute	singed and roasted in pit	Fowler 1989:24
ground squirrel	Tepehuan	skinned, eviscerated, roasted on spit or in coals	Pennington 1969: 124
ground squirrel	Seri	eviscerated, fur singed off, pit-baked	Felger and Moser 1991:53
tree squirrel	Northern Paiute	roasted in sand	Fowler 1989:24
tree or rock squirrels	Southern Paiute	roasted in ashes about 2 hours, then skinned	Kelly 1964:52
prairie dog	Northern Ute	entrails removed, then roasted in coals	Smith 1974:49
prairie dog	Northern Paiute	roasted in sand	Fowler 1989:24
prairie dog	Southern Paiute	tossed into fire, then removed, scraped, and eviscerated; belly pinned with twigs, baked in ashes, sometimes boiled	Kelly 1964: 157
prairie dog	NE Yavapai	cooked in hot ashes after gutting and skinning	Gifford 1936: 266

(Table continued on next page)

(Table 10.18, continued from previous page)

Prey taxon	Affiliation	Treatment	Reference
prairie dog	Navaho	clean with or without removing fur, salt, bake in hole in ground	Bailey 1940:284
groundhog	Northern Paiute	gutted, then sewn up, roasted in the skin under coals	Fowler 1989:25
quail	NE Yavapai	eggs and birds cooked in ashes	Gifford 1936: 267
quail	Pima Bajo	picked, eviscerated, roasted on a spit	Pennington 1980:194
dove	NE Yavapai	cooking in ashes without eviscerating or picking	Gifford 1936: 267
dove and quail	Havasupai	pit baked in wet sand	Weber and Seaman 1985:63
various small birds	NE Yavapai	cooking in ashes without eviscerating or picking	Gifford 1936:267
crow	W Yavapai	cooked in ashes or boiled	Gifford 1936: 267
chachalaca	Pima Bajo	eviscerated, roasted on a spit	Pennington 1980:194
unspecified lizards	Southern Paiute	eaten in summer, roasted in ashes	Kelly 1964:182
unspecified lizards	Digueno	roasted or pounded and stewed	Cuero 1970:32-33
chuckwalla	Mohave	Roasted in ashes, weighted with stone	Stewart 1968:36
chuckwalla	W and NE Yavapai	cooked in hot ashes, gutted or ungutted	Gifford 1936: 268
turtles, tortoises, snakes, lizards	Seri	boiled with salt	Malkin 1962: 22-23
land turtle	Pima Bajo	removed from shell, cooked in olla briefly, then fried	Pennington 1980:236
land turtle	Comanche	roasted live in fire, then shell cracked	Smith and Smith 1977:90-91
aquatic turtle	Pomo	placed on fire, when shell cracks open, meat is removed and broiled on coals; or placed unopened in ashes to bake	Barrett 1952: 105
rattlesnake	Tepehuan	rattles and head cut off, skinned, cooked for an hour in an olla	Pennington 1969:144
snakes	Digueno	roasted or pounded and stewed	Cuero 1970:32-33
marmot	Southern Paiute	roasted in skin, sometimes boiled	Kelly 1964:52

(Table continued on next page)

(Table 10.18, continued from previous page)

Prey taxon	Affiliation	Treatment	Reference
rabbit	Northern Ute	skinned, split in half, entrails removed, then boiled	Smith 1974:49
rabbit	Southern Paiute	roasted for an hour in ashes, pelt left on in summer, pelt removed and used in winter; ribs, vertebrae, and long bones sometimes pounded on mortar	Kelly 1964:52, 182
rabbit	Northern Paiute	skinned, bones ground and boiled; extra carcasses dried, then boiled whole or pounded to make soup	Wheat 1967:14
rabbit	Shoshoni	abdomen slit, entrails evacuated, then replaced, cooked in hot ashes	Lowie 1924:197
rabbit	Western Yavapai	cooked in ashes or boiled; preserved several days by skinning, charring slightly, and hanging up	Gifford 1936: 266
rabbit	Mohave	skinned, legs broken, folded under and stuck into carcass, tied up; roasted in ashes; pounded meat and bones on mortar, roasted again	Stewart 1968:36
rabbit	Pima Bajo	skinned, eviscerated, roasted on a spit or sometimes boiled	Pennington 1980:201
rabbit	Cahuilla	singed, then skinned and eviscerated, liver and entrails eaten separately	Lando and Modesto 1977:110
rabbit	Luiseño	broiled on coals; or baked in earth oven, sometimes pounded entire in mortar, then eaten or preserved	Sparkman 1908: 198
rabbit	Wappo	pounded (including bones, entrails, ears) and roasted	Driver 1936:186
rabbits and rodents	Seri	roasted on a spit or baked in a pit	Felger and Moser 1991:53

(End of Table 10.18)

Illustrations of the Hearth Deposit Faunal Assemblage

Figures 10.37 to 10.52 present a gallery of photographs illustrating the range of taxa and elements from the hearth deposit (the first photograph also includes one item from the ambient bone assemblage). Mammals are shown first, followed by amphibian, snake, lizard, and fish bone.

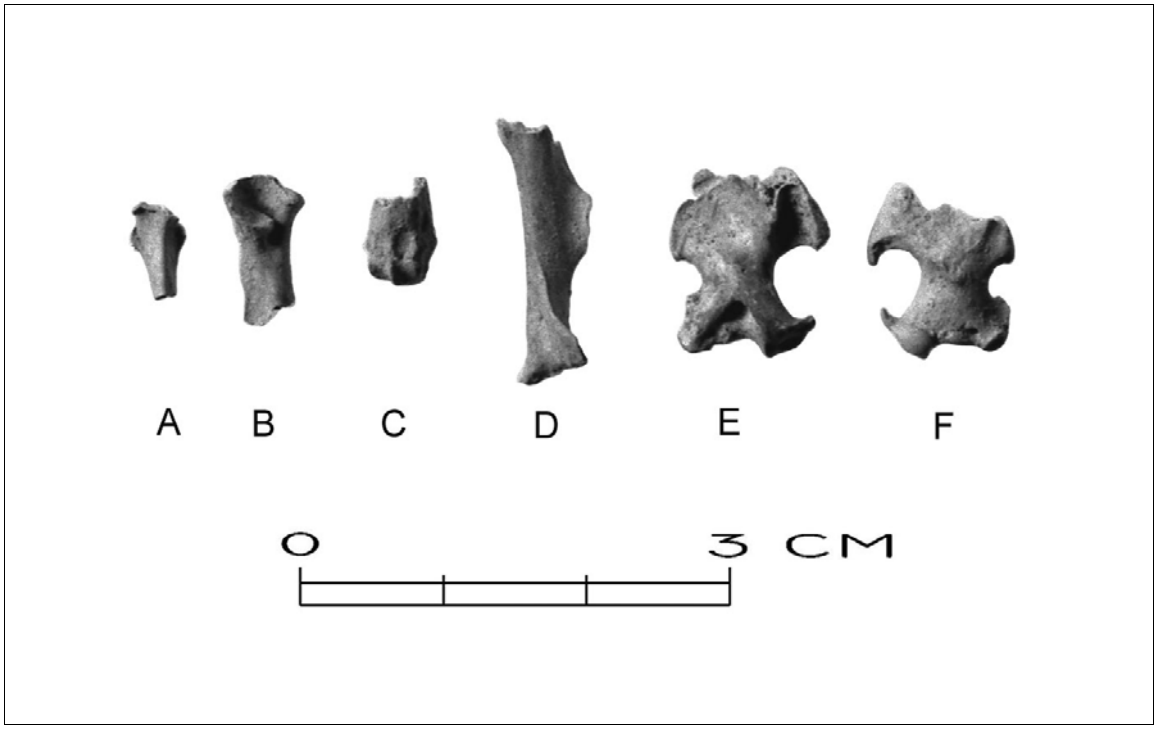


Figure 10.37. Hearth Deposit and Ambient Bone: Eastern Mole, Gopher, Leporid.

Hearth deposit (N113 E98, 92.40-92.30 m, lot B-107)

A, *Scalopus aquaticus*, right proximal femur fragment, anterior view

B, *Neotoma* sp., right ischium, ventrolateral view

D, *Geomys attwateri* or *G. personatus* left humerus

E, *Scalopus aquaticus*, right humerus, posterior view

F, *Scalopus aquaticus*, right humerus, anterior view

Ambient bone (N113 E98, 92.20-92.15 m, lot B-108). See Fig. 9.11 for location underlying the hearth deposit

C, cf. Leporidae, distal metapodial fragment, posterior view

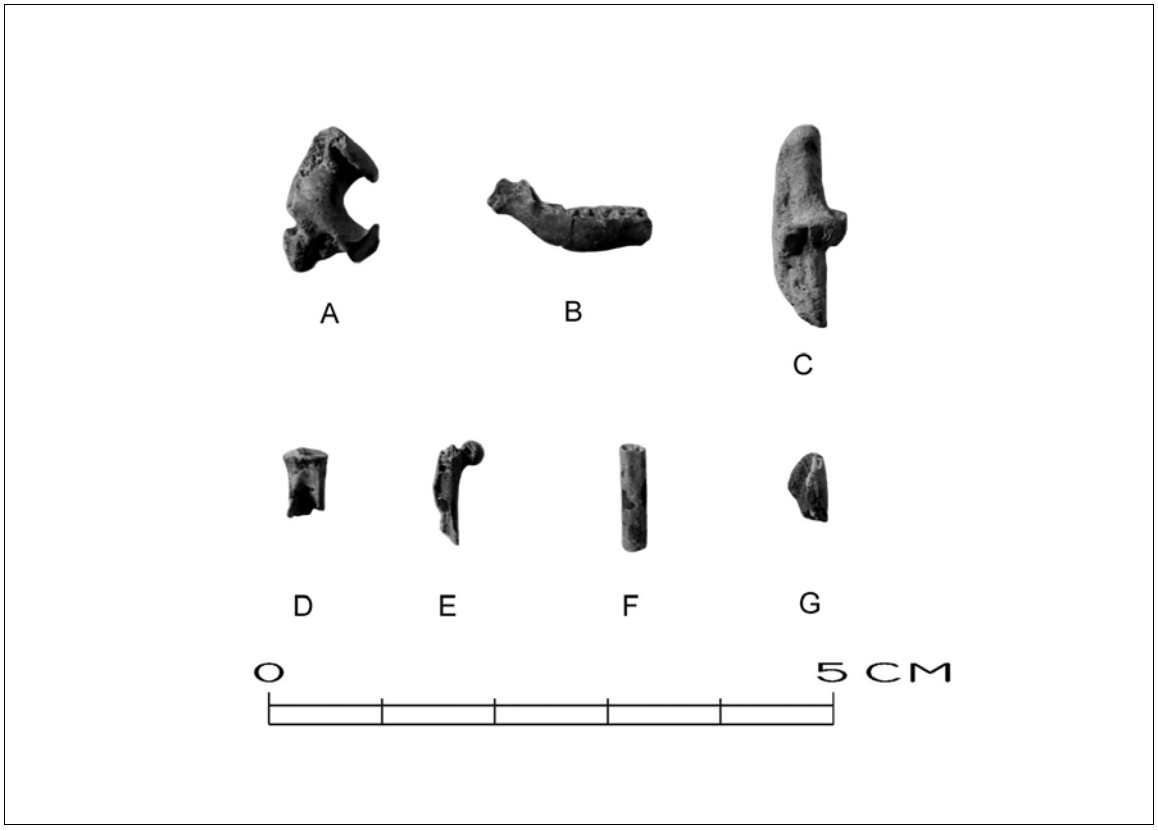


Figure 10.38. Hearth Deposit: Eastern Mole, Woodrat, Rabbit, Frog, Unidentified. A, *Scalopus aquaticus*, right humerus, posterior view; B, *Scalopus aquaticus*, right edentulous mandible, labial view; C, *Sylvilagus* sp. left calcaneum (unfused epiphysis at bottom); D, *Neotoma* sp., left scapula fragment, glenoid fossa at top; E, right proximal femur fragment of unidentified rodent, anterior view; F, long bone shaft fragment from unidentified frog (orientation uncertain); G, calcined bone fragment from unidentified mammal. Unit 2, Feature 5 surface and adjacent area, lot B-149.

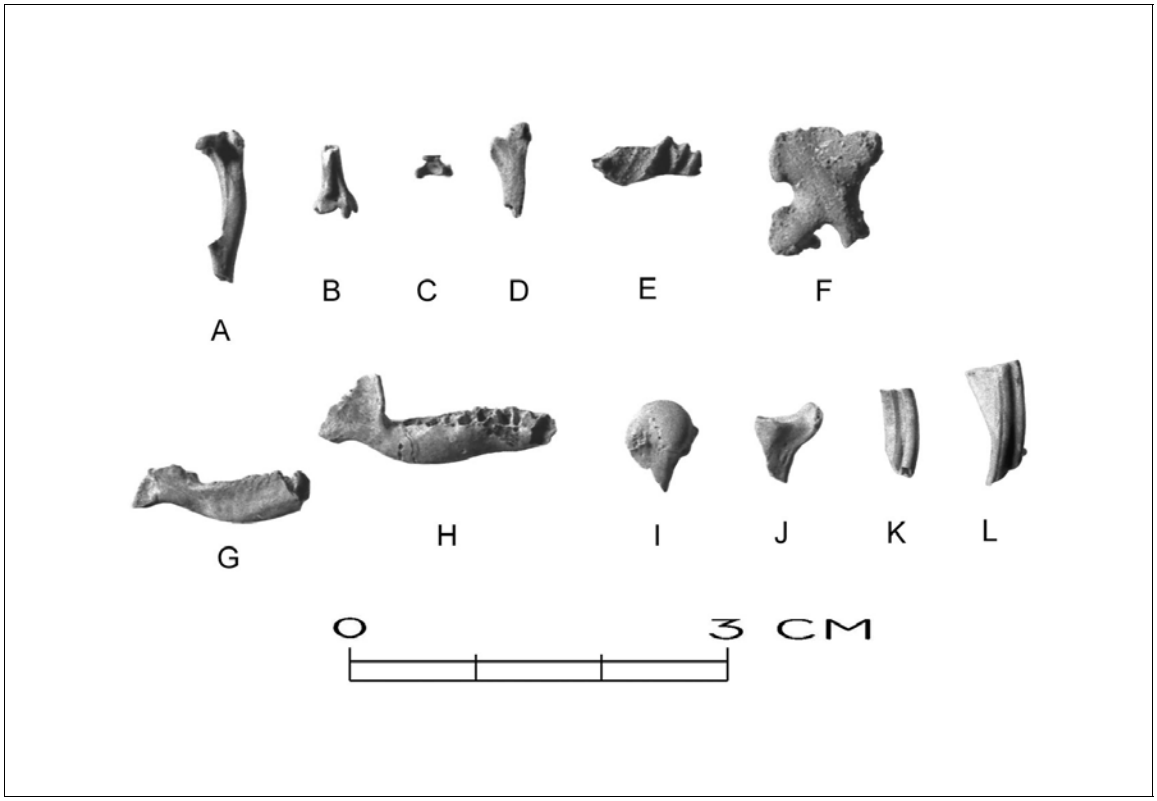


Figure 10.39. Hearth Deposit: Eastern Mole, Gopher, Rabbit Bone. All from N113 E98 (92.50-92.40 m), lot B-105. These items come from different clusters of bone recognized in the floor of the excavation unit.

Scalopus aquaticus: A, proximal right tibia, posterior view, Group 1h; B, distal left tibia, anterior view, Group 1h; C, carpal, orientation uncertain, Group 1h; F, right humerus, posterior view, Group 1j; G, left edentulous mandible fragment, medial view, Group 1 Residual; H, right edentulous mandible, lateral, Group 1 Residual.

Unidentified *Neotoma*-sized mammal: D, rib head, Group 1h.

Sylvilagus sp.: E, left mandible fragment with alveoli for P_3-P_4, medial view, Group 1h.

Geomys sp.: I, left proximal humerus fragment, posterior view, Group 1 Residual; J, glenoid fossa of right scapula, medial view, Group 1 Residual; K, left P_4, labial view, Group 1 Residual; L, right I^1, dorsal view, Group 1 Residual.

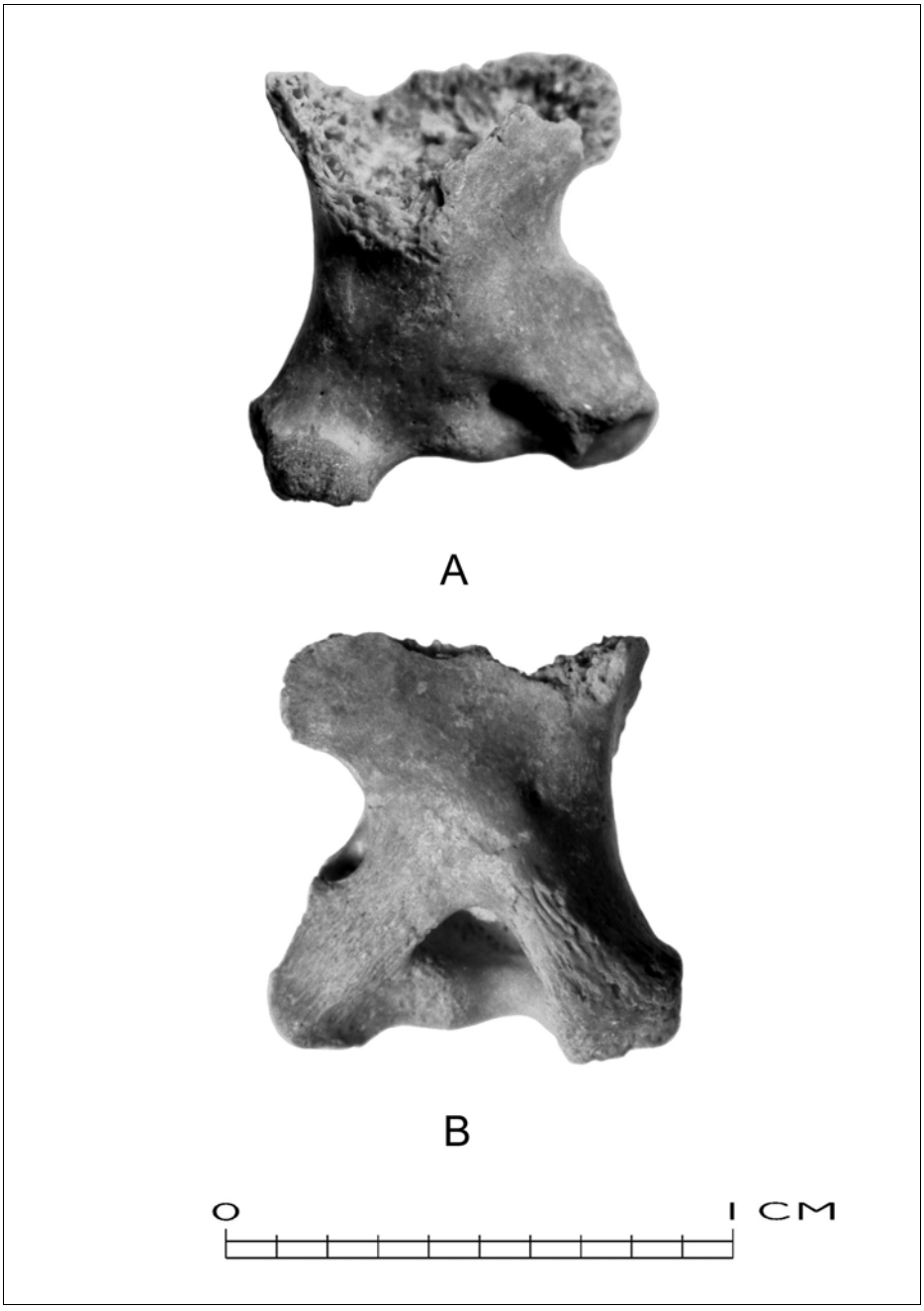


Figure 10.40. Hearth Deposit: Eastern Mole Humerus. A, anterior view; B, posterior view of same specimen. Fragmentary right humerus of *Scalopus aquaticus* (smaller of two in this lot). Breakage seen at top of "A" is old (pre-excavation), interior has carbonate deposits. From unanalyzed lot B-107A (N113 E98, approximately upper 5 cm of 92.40-92.30 m level), coarse fraction from wet-sieved loose matrix.

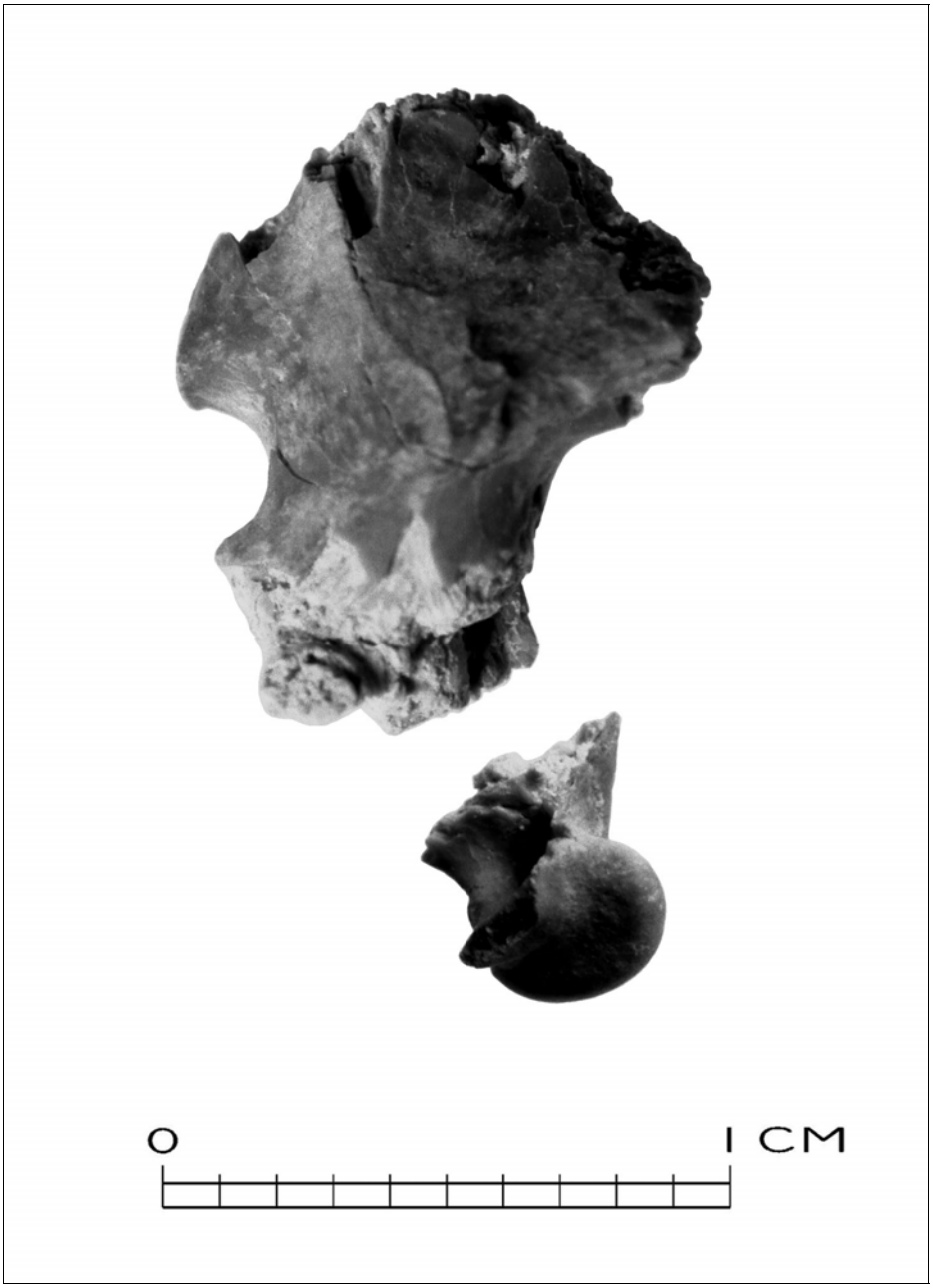


Figure 10.41. Hearth Deposit: Additional Eastern Mole Humerus Fragments. Fragments of a right humerus of *Scalopus aquaticus* (larger of two in this lot). Specimen shows old breakage, surface cracking and flaking, and extensive carbonate deposition in the interior. From unanalyzed lot B-107A (N113 E98, approximately upper 5 cm of 92.40-92.30 m level), coarse fraction from wet-sieved loose matrix.

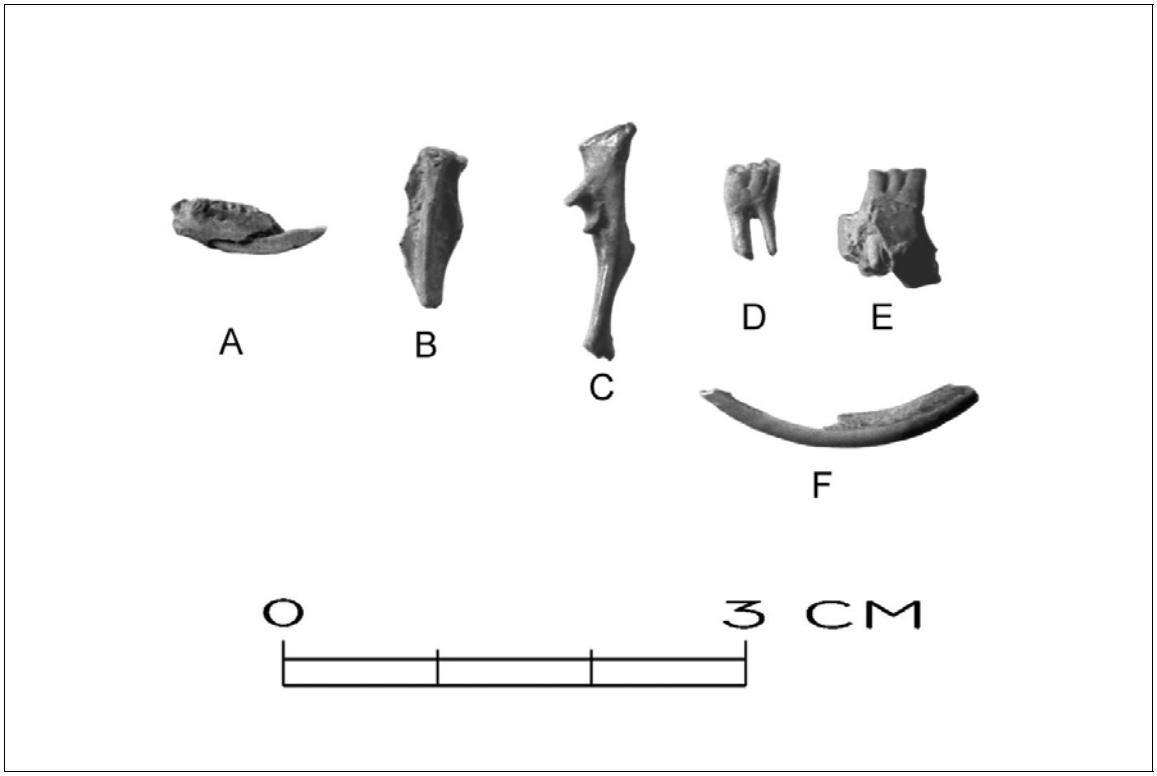


Figure 10.42. Hearth Deposit: Rodent and Insectivore Bone. These items come from different clusters of bone recognized in the floor of the excavation unit. A, *Chaetodipus hispidus*, left edentulous mandible, medial view, Group 1 Residual; B, Heteromyidae, left proximal tibia (juvenile), posterolateral view, Group 2; C, *Scalopus aquaticus*, right ulna, medial view, Group 3; D-F, teeth from *Neotoma* sp., all Group 4 and probably all the same individual (D, right M_2, E, right M_1, F, lateral view of large incisor). N113 E98 (92.50-92.40 m), lot B-105.

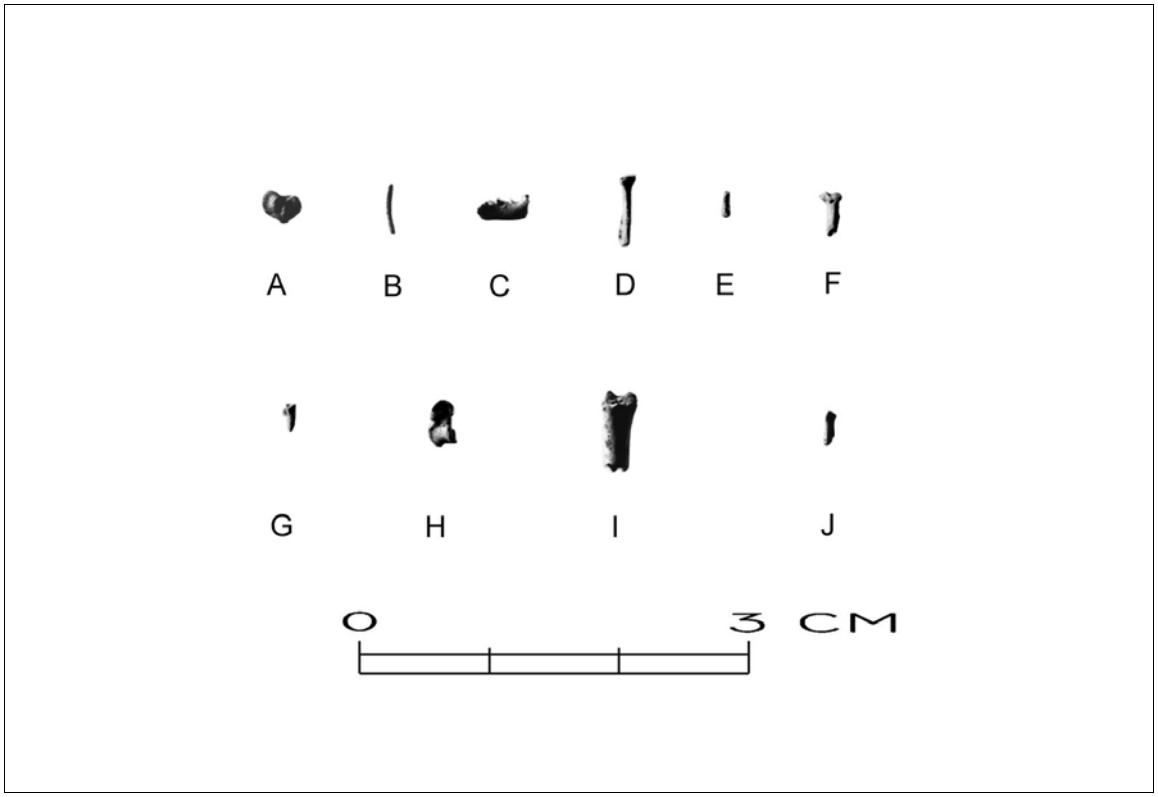


Figure 10.43. Hearth Deposit: Rodent, Insectivore, Bird, Unidentified Bone. A, proximal epiphysis of unidentified rodent tibia; B, small baculum from unidentified rodent; C, Soricidae (probably *Cryptotis parva*), left mandible fragment; D, unidentified bird, radius fragment; E, F, unidentified bird long bone fragments; G, claw from unidentified small vertebrate; H, astragalus from unidentified small vertebrate; I, proximal radius fragment from unidentified juvenile small mammal; J, phalanx from unidentified vertebrate. All this material is from the hearth deposit in N113 E98 (92.443-92.400 m, lot B-106). Considered unidentifiable in the initial study, it was identified by Alisa Winker in September, 1987.

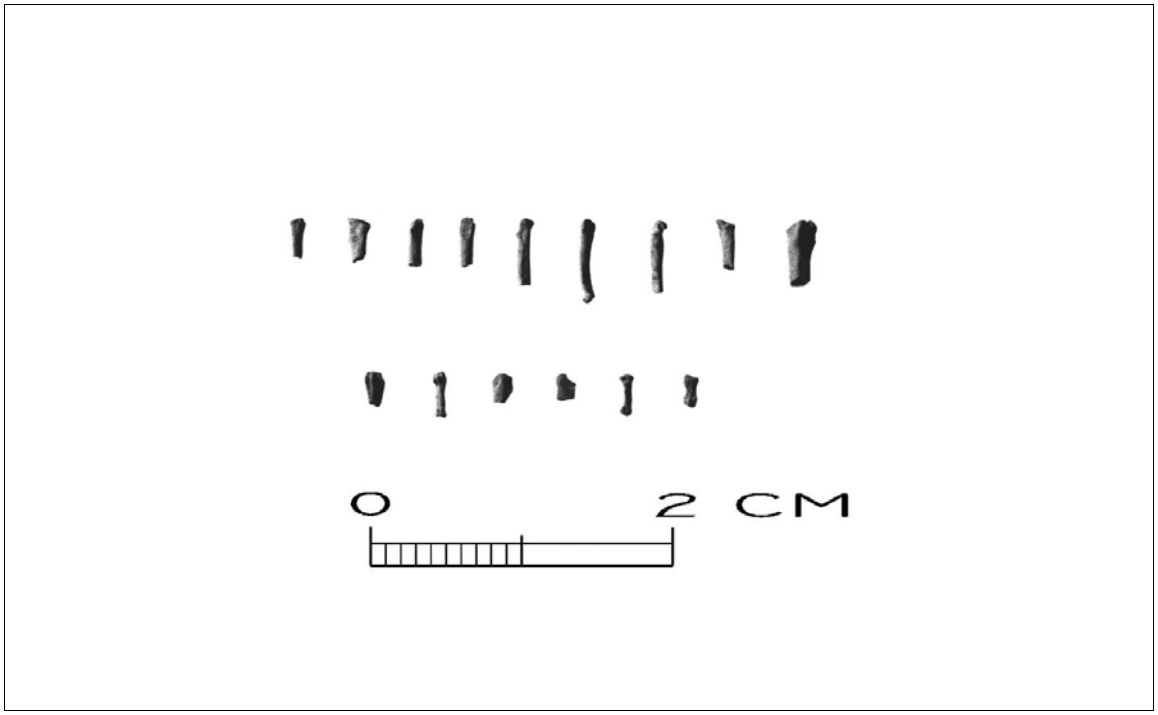


Figure 10.44. Hearth Deposit: Small Mammal Metapodials. A variety of small mammal metapodials (orientation uncertain) from N113 E98 (92.443-92.400, lot B-106). These are all from material initially sorted as unidentifiable, later identified by Alisa Winker in September, 1987.

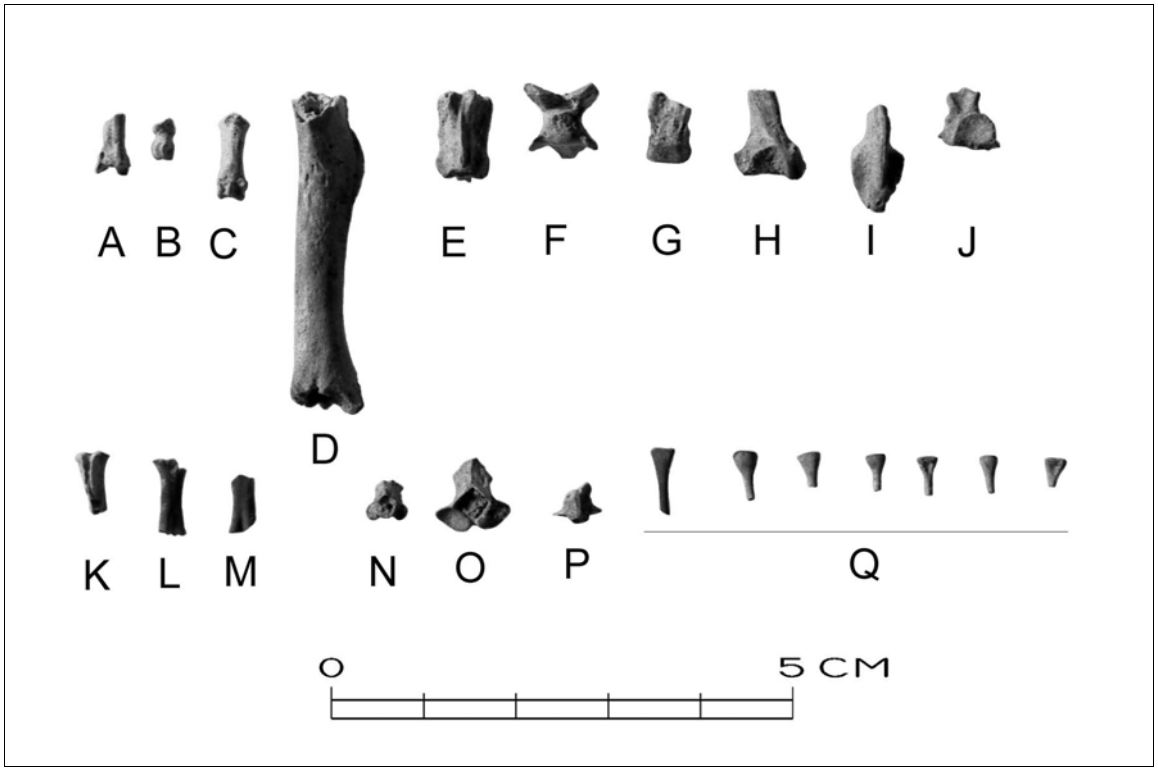


Figure 10.45. Hearth Deposit: Rodent and Amphibian Bone. A, *Chaetodipus/ Perognathus* sp., right distal tibia, lateral view; B, C, *Geomys* sp. metacarpals, posterior view; D, *Neotoma* sp. right femur, posterior view; E-G, *Neotoma* sp. or *Neotoma*-sized rodent, caudal vertebrae, various views; H-J, unidentified frog or toad pelvic fragments; K, frog or toad urostyle fragment, dorsal view; L, M, unidentified frog or toad radius/ulna fragments; N-P, unidentified frog or toad atlas vertebrae, posterior view; Q, group of seven unidentified salamander limb bone fragments, orientation uncertain (likely *Ambystoma texanum*). All from N113 E98 (92.443-92.400 m, lot B-106).

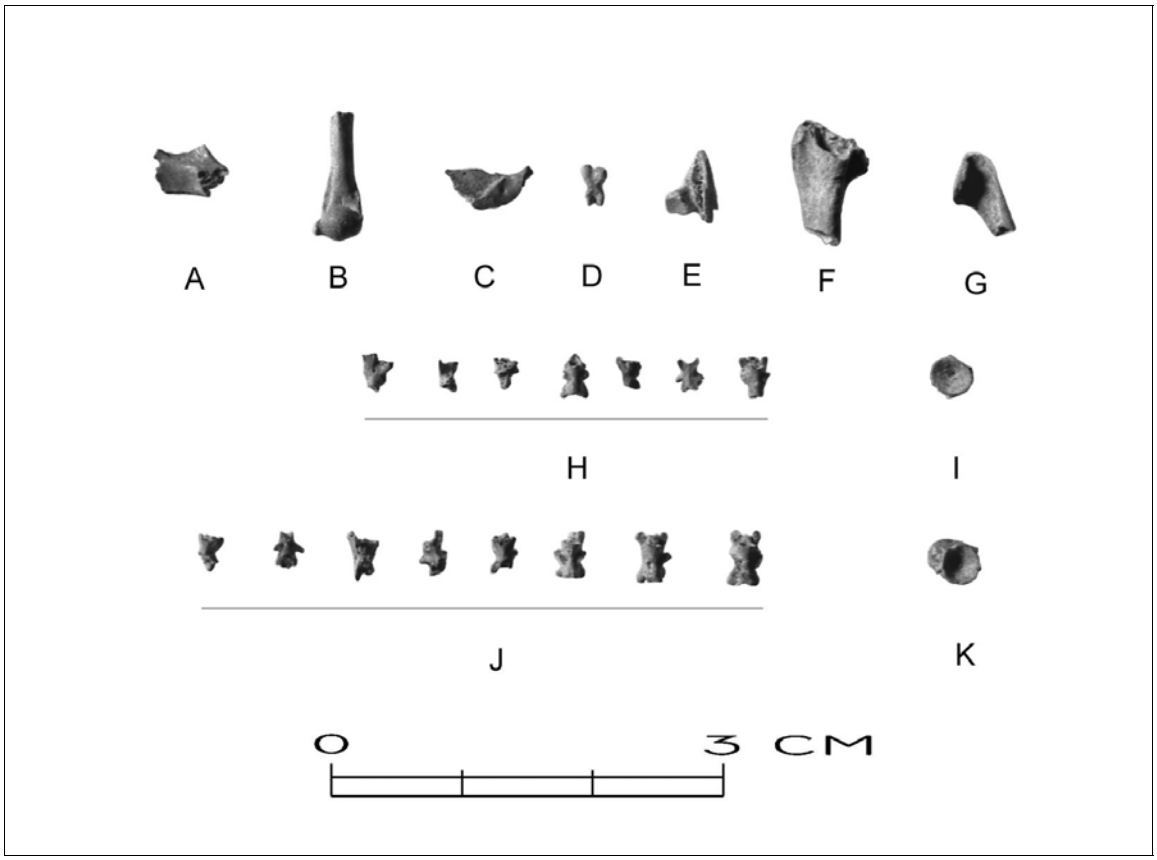


Figure 10.46. Hearth Deposit: Rodent, Amphibian, Bird and Fish Bone. These items come from different clusters of bone recognized in the floor of the excavation unit. A, *Onychomys leucogaster* distal right mandible fragment, lateral view, Group 1a; B, frog or toad left distal humerus fragment, anterior view, Group 1a; C, *Chaetodipus/Perognathus* sp. right mandible fragment, lateral view, Group 1b; D, phalanx from *Neotoma*-sized mammal, lateral view, Group 1d; E, pelvis fragment from *Neotoma*-sized mammal, lateral view, Group 1d; F, *Geomys* sp. right proximal femur fragment, anterior view, Group 1f; G, lower beak of small passerine bird, Group 1g; H, J, group of 15 salamander vertebrae, Group 1g; I, K, fish vertebrae, Group 1g. All from N113 E98 (92.50-92.40 m), lot B-105.

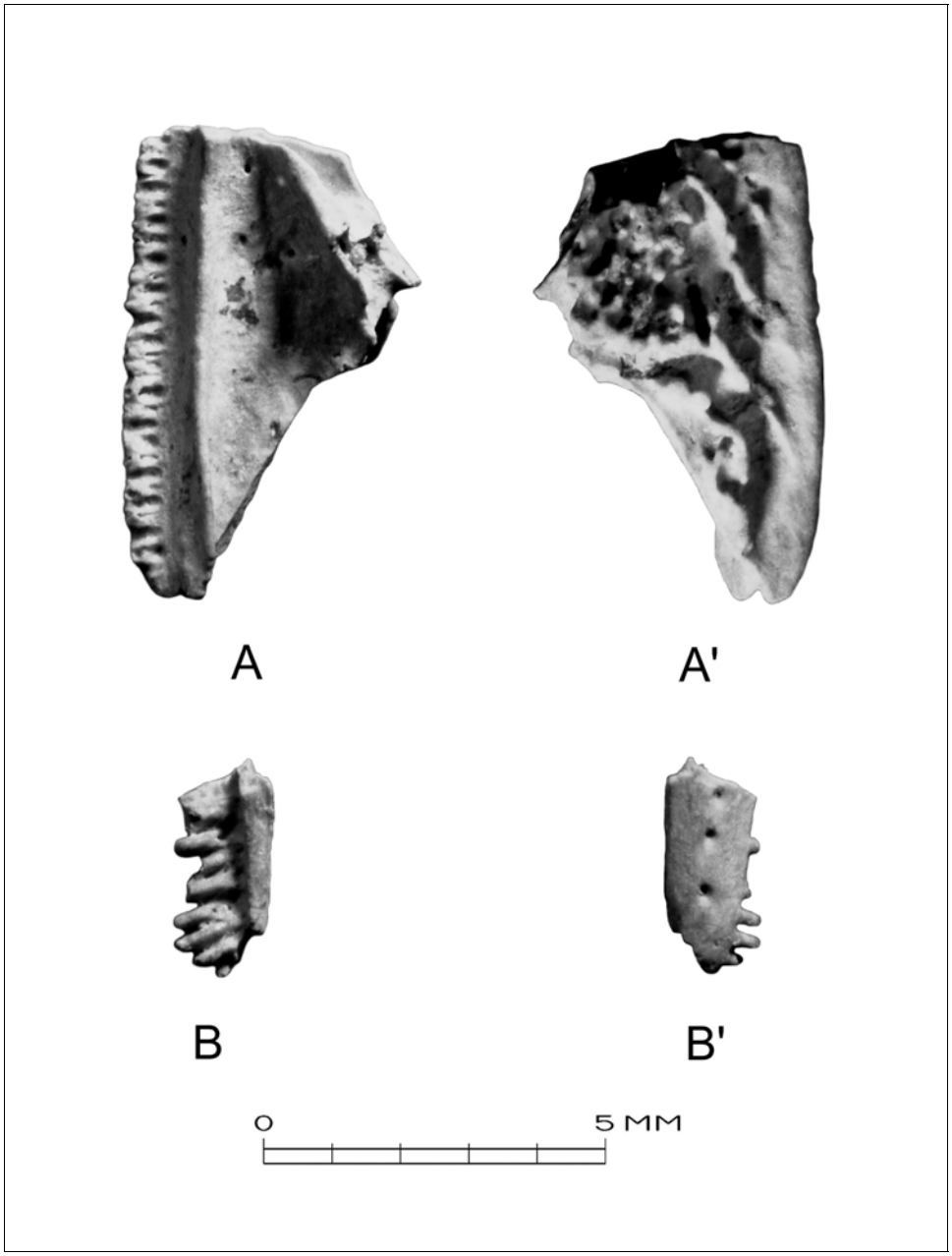


Figure 10.47. Hearth Deposit: Amphibian and Lizard Dentition Fragments. From N113 E98 (approximately upper 5 cm of 92.40-92.30 m), lot B-107A. This lot has not been formally studied, but selected items have been noted and photographed. A, A', interior and exterior surfaces of unidentified maxillary fragment (cf. *Rana catesbeiana?*); B, B', interior and exterior surfaces of unidentified lizard dentary. A is probably from a large frog, but the heavy surface ornamentation seen in A' does not seem typical of *R. catesbeiana.*

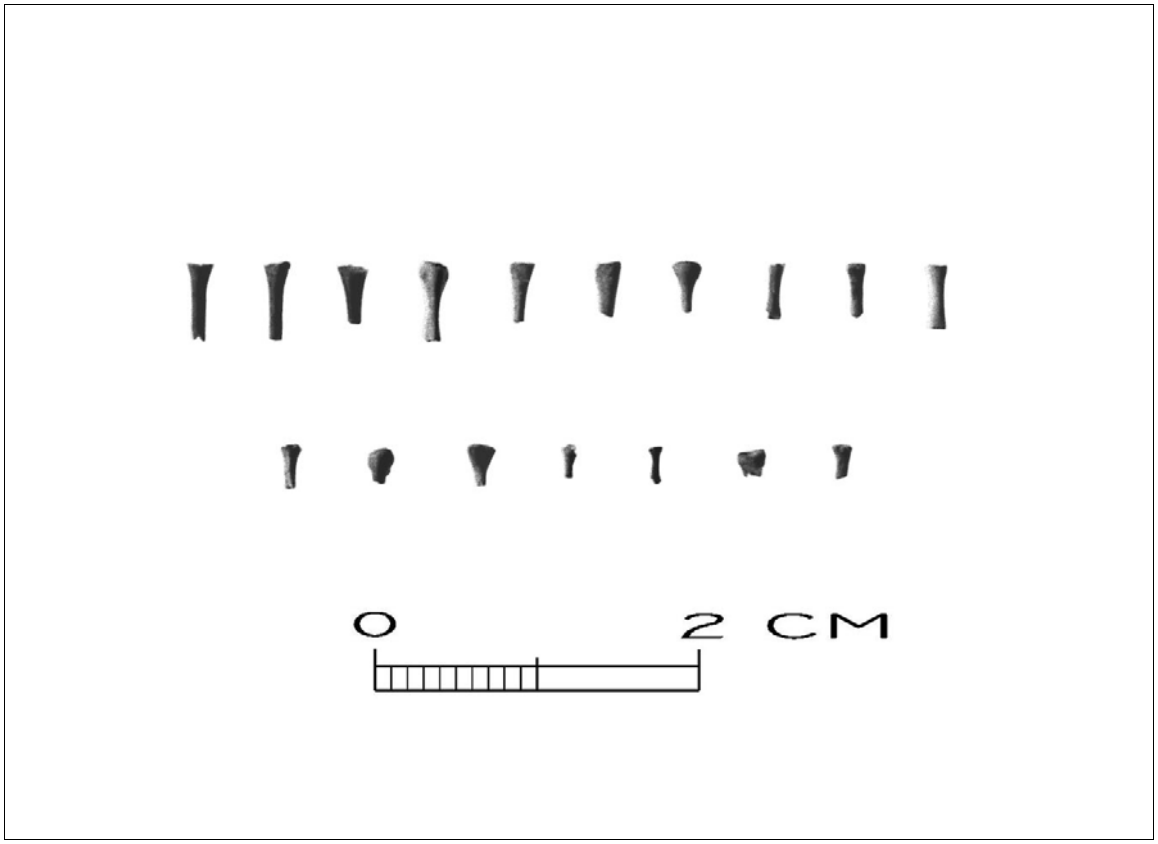


Figure 10.48. Hearth Deposit: Salamander Long Bone Fragments. A variety of salamander long bones and long bone fragments from N113 E98 (92.443-92.400 m, lot B-106), orientation uncertain. This is all material initially sorted as unidentifiable, but later identified by Alisa Winker in September, 1987.

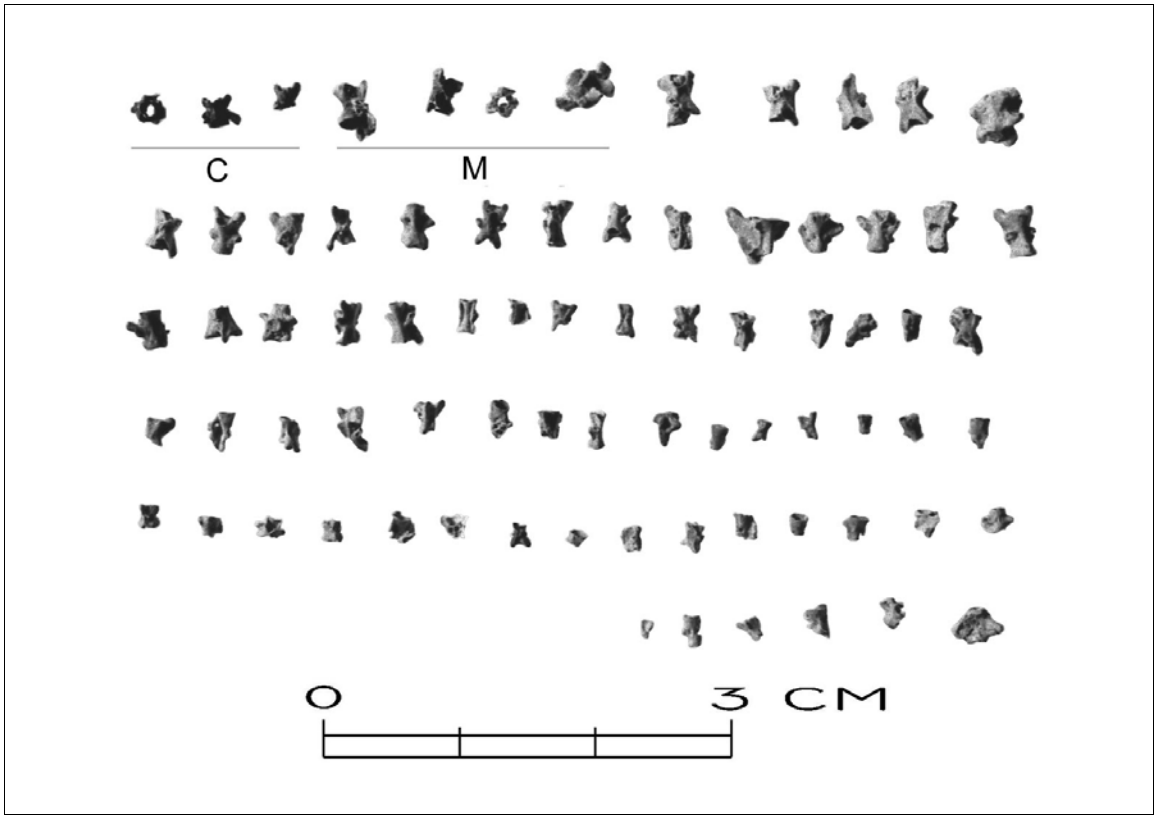


Figure 10.49. Hearth Deposit: Salamander Vertebrae. Top row, first three vertebrae ("C") are charred; next four vertebrae ("M") are manganese-stained. This is a selection from the 90 specimens in this lot. N113 E98 (92.443-92.400 m), lot B-106, sieved loose fill, coarse fraction.

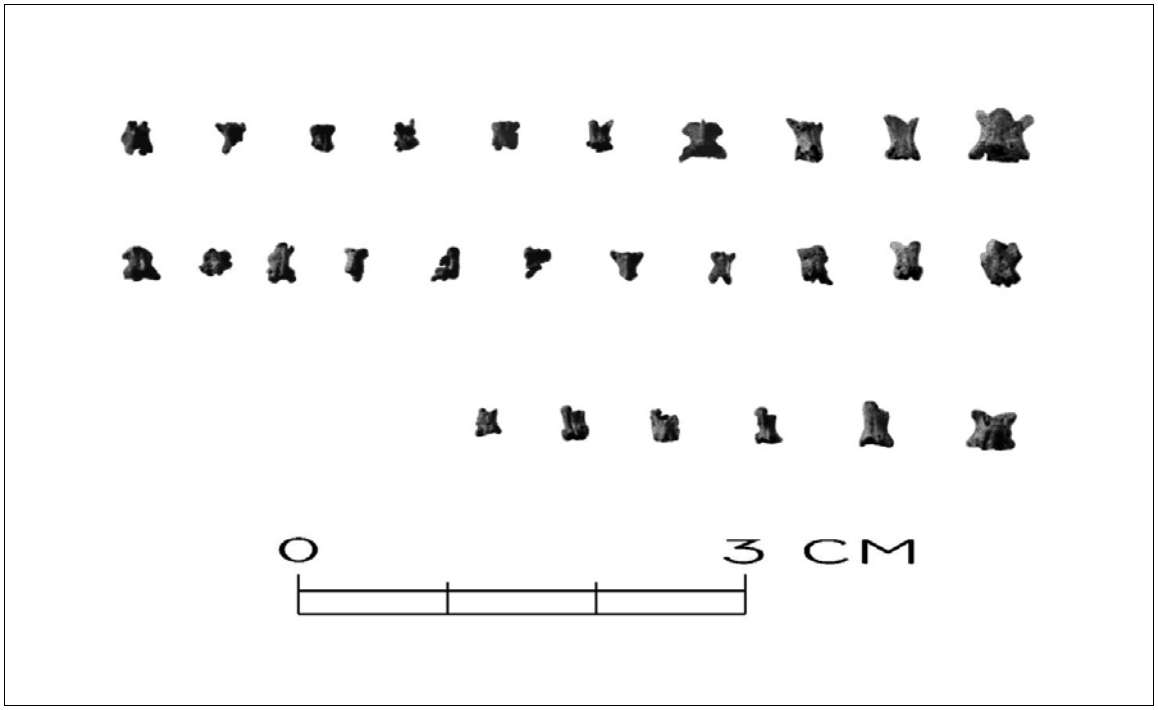


Figure 10.50. Hearth Deposit: Snake and Lizard Vertebrae. Top two rows, snake vertebrae; bottom row, lizard vertebrae. All from N113 E98 (92.443-92.00 m), lot B-106, sieved loose fill, coarse fraction.

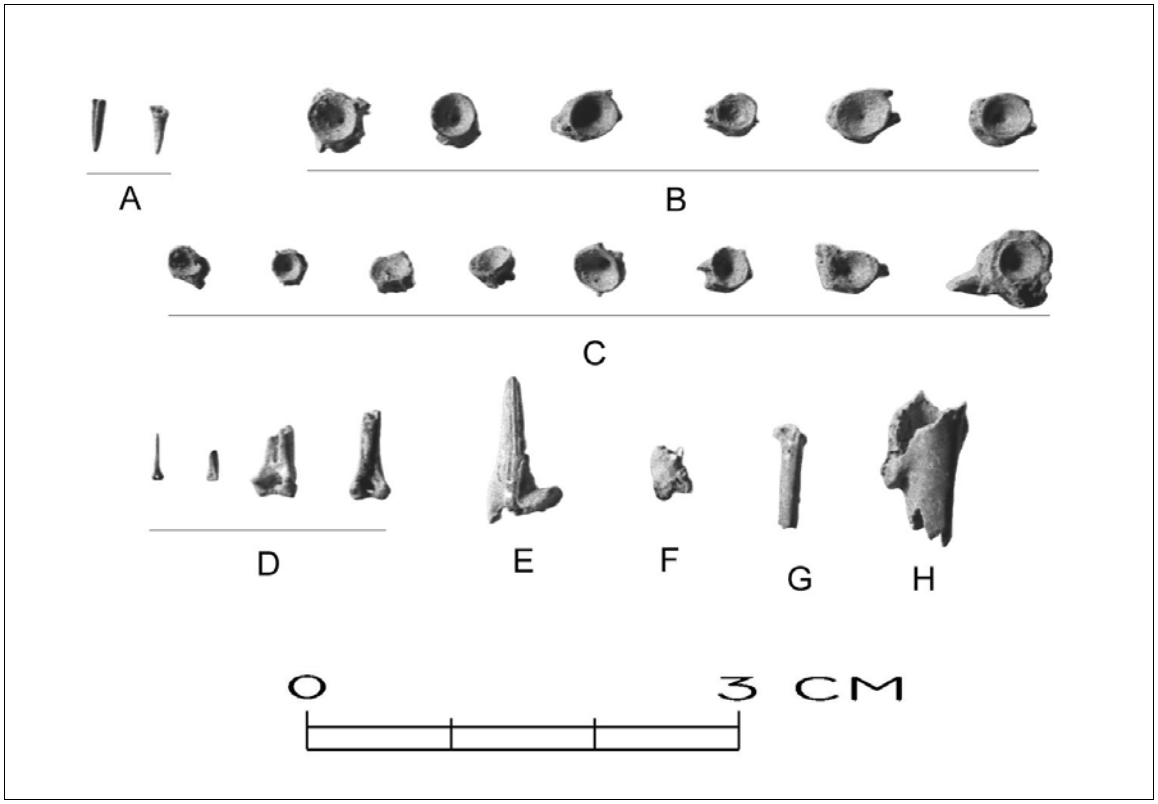


Figure 10.51. Hearth Deposit: Fish and Bird Bone. A, two fish teeth (orientation uncertain); B, six fish vertebrae; C, eight fish vertebrae; D, four fish dorsal fin spines of various sizes; E, fish pectoral fin spine; F, left proximal carpometacarpus (medial view) of a small bird; G, left proximal ulna (dorsolateral view) of small bird; H, left proximal carpometacarpus (lateral view) of bird. N113 E98 (92.443-92.400 m), lot B-106, sieved loose fill, coarse fraction.

Gas Chromatographic Analysis of Sediment Lipids

One important question that can be asked about the hearth deposit bone assemblage is whether the bones arrived at the site completely defleshed, or accompanied by any kind of soft tissue residue. In January, 1990, I submitted three very small sediment samples (4.2-6.1 g) to Michael Marchbanks to check for plant or animal lipids preserved in the bench sediments. A number of different fatty acids were found to be present in the samples (lipids include fatty acids, sterols, alcohols, aldehydes, and hydrocarbons; Marchbanks 1991).

The sediment samples were extracted with a cleaned stainless steel spatula. Sample "A" (4.2 g) was scraped from the baked surface of the hearth, Feature 5, which had 10 years previously been removed from the site in a block and curated in the archeology laboratory. For comparison with the hearth sample, two background samples at about the same elevation, but some distance away were analyzed. Sample "B" (5.6 g) was removed from the bagged matrix sample collected in the southwest corner of unit N113 E98 (92.40-92.30 m), and a second background sample was removed from the matrix sample collected in the southwest corner of unit N112 E99 (92.40-92.35 m). Figure 10.52 shows the location of these samples. The general location of the hearth deposit, or microvertebrate bone bed, is also shown in very schematic fashion – the actual limits of the bone bed are unknown and were not visible in the floors of the excavation units (see Fig. 10.4).

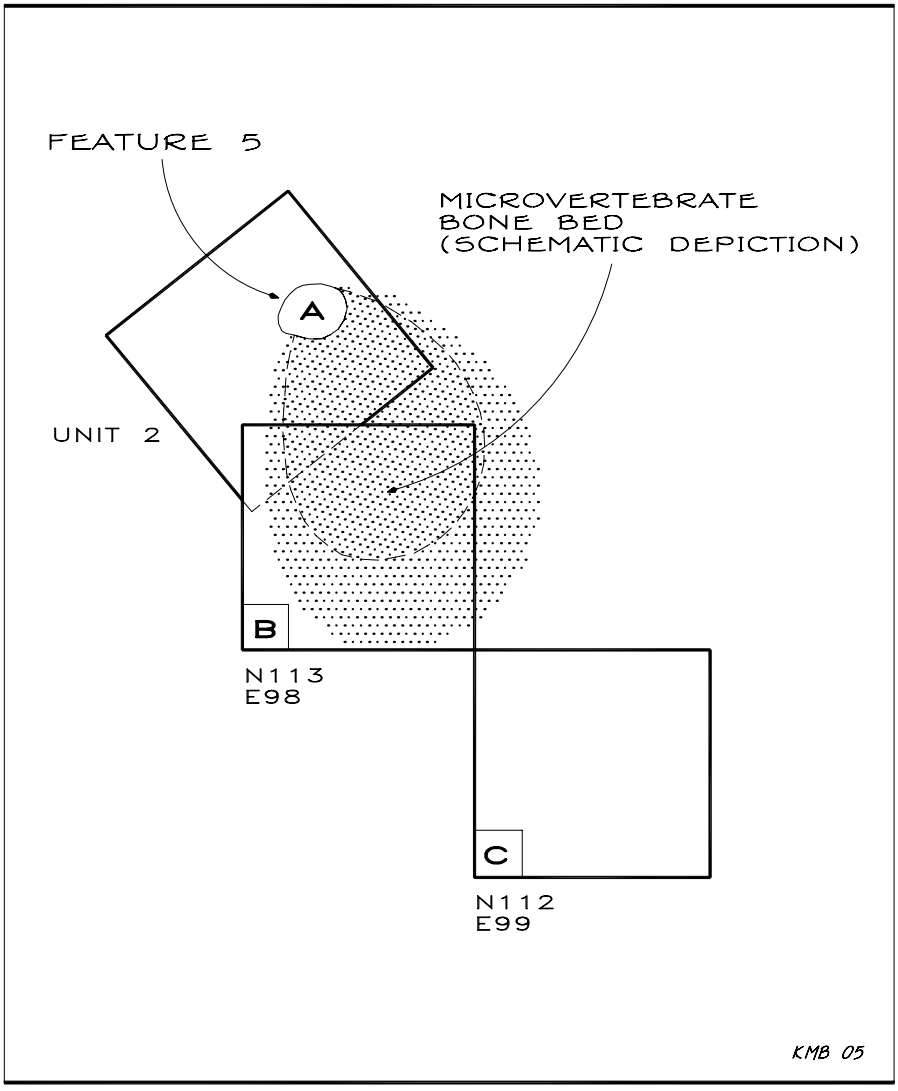


Figure 10.52. Location of Lipid Samples. The extent of the hearth deposit bone bed is shown very schematically – the actual limits are unknown. A, B, and C are the three samples analyzed.

The analysis protocol is as follows:

> Lipids were extracted from the soil samples utilizing the methodology described in Marchbanks (1989). The soil sample… was then ground into dust and stored in glass vials (in a freezer) until lipid extractions were conducted. The lipids were extracted in a Soxhlet extractor (70° C) in a 2:1 chloroform:methanol solvent for approximately seven hours. The solvent was then evaporated and the organic

> residues converted to methyl esters. The fatty acids were separated from the other forms of lipids by thin-layer chromatography in a neutral lipid tank. The samples were then analyzed on a Hewlett-Packard GC (gas chromatograph) with a 30 meter 0.25 mm-ID DB-5 capillary column using temperature ramp programming. The peaks were "identified" by a combination of their retention times and known standards (Marchbanks 1991).

The results of the analysis are shown in Table 10.19, which shows the percentage of saturated fatty acids. The acids are identified in the table by structural form rather than name (for example, C12:0). The "C" stands for carbon, the 12 for the number of carbons, and the 0 for the number of double bonds in the chain (if there are no double bonds, it is a *saturated fatty acid*; one with a single double bond is *monounsaturated,* and one with two or more is *polyunsaturated*). Numbers without colons represent acids labeled only by retention time.

The analysis shows that the hearth sample differs from the two background samples in having a much more diverse array of acids preserved in small quantities. According to Marchbanks

> …the hearth has between 4.84 and 5.71 times more organic residues (fatty acids) than the two samples which can be utilized as background or controls.
>
> The %S is just the percent of saturated fatty acids present in the sample; for reasons discussed elsewhere (Marchbanks 1989) just the fatty acids C12:0 and C14:0 represent the saturated fatty acids, while C18:2 and C18:3 represent the unsaturated ones. The higher the %S value, the more likely the residue reflects the presence of faunal residues, while lower values tend to reflect floral parent materials. The two matrix samples are fairly similar to each other and other soil samples that have been analyzed by the author. They mostly contain straight-chain fatty acids with no double bonds and very few diagnostic fatty acids. The high %S ratios of these two samples [are] also characteristic of background or "blank" samples since fatty acids naturally degrade and occur in the form of straight chains. The hearth sample, on the other hand, is very different in concentration and characteristic of faunal parent materials. There is very little

evidence for floral residues within this sample. In addition, the %S ratio (74.96) is well within the normal range for faunal residues (Marchbanks 1991).

Table 10.19. Results of Lipid Analysis.

Acid	Sample A	Sample B	Sample C
	F5	N113 E98	N112 E99
3.02	0.02		
C12:0	0.97	0.51	1.56
C13:0	0.35		
C14:0	3.25	2.04	1.91
4.31	0.43		
C15:0	0.79		
C16:0	41.21	45.24	41.56
C16:1	2.63		
5.88	0.22	3.29	
6.14	3.21	12.37	12.29
C17:0	1.53		
C18:0	30.84	26.31	24.05
8.59	2.59		
C18:1	8.52	9.38	16.97
C18:2	1.27	0.54	0.82
C18:3	0.14	0.32	0.84
14.69	1.81		
C20:0			
C22:0	0.22		
C20:1			
C22:1			
Total area	43291.90	12978	10115
%S	74.96	67.64	74.78

Plants are low in saturated fatty acids, land animals are high, and fish are intermediate (Marchbanks 1989:Fig. 10). The lipid analysis is significant because it suggests the bone deposit may have been accompanied by some sort of chemical residue from animal fats when it was originally deposited. Domestic rats and mice are about 24-

35% lipids by dry weight (Clum 1997:Table 2). Table 10.20 shows fat and energy content for some of the hearth deposit species (or congeneric species when the appropriate species could not be found). Among other things, this suggests the deposit is not a lag deposit of defleshed animal bones deposited by flooding. Likewise, it suggests the hearth deposit is not a raptor pellet midden, because raptor digestive systems are very efficient and acidic, and essentially remove nearly all the soft tissue from the prey before a pellet is ejected. It also suggests that the southwest corner of the N113 E98 excavation unit is essentially beyond the limits of the bone bed.

INTERPRETATION OF THE HEARTH DEPOSIT

This chapter is concerned mainly with vertebrate remains as paleoenvironmental indicators, not as cultural debris, so even though I regard much of the faunal assemblage as "artifacts," (in the sense of items transported and modified by humans), I will present only a condensed synopsis of the cultural context. "Agency" (who transported the vertebrate remains, and why) is relevant to environmental context because different kinds of predators have different foraging radiuses, collection biases, and capabilities.

I have already shown that the bench sediments contain a background scatter ("ambient bone") of small vertebrates distributed through the deposits in low density, but the remarkable microvertebrate bone bed ("hearth deposit") extending outward and downstream from Feature 5 is much more concentrated (though largely similar in composition) than the ambient bone. To explain this extraordinary concentration of bone, three scenarios seem possible:

Table 10.20. Proximate Composition of Some Prey Species and Congeners.

	% crude fat	% lipid	kcal/g	Source
Snakes, various			6.51	1
Lizards, various			5.50	1
Rana clamitans	10.2		4.80	1
Peromyscus leucopus	19.9		5.51	1
Peromyscus maniculatus	14.38			3
Peromyscus maniculatus	15.67		5.20	4
Peromyscus maniculatus		17.49-19.65	5.05-5.14	2
Perognathus spp. mean	11.65		4.91	4
Dipodomys spp. mean	10.15		4.84	4
Neotoma lepidus	7.64		4.81	4
Onychomys torridus	20.79		5.39	4
Microtus ochrogaster		14.59-16.08	4.65	2
Microtus pennsylvanicus	15.5		5.34	1
Lepus californicus	4.5		4.54	1

Sources:

1. Dierenfeld, Alcorn and Jacobsen (2002:Table 1)
2. Fleharty, Krause and Stinnett (1973:Tables 1, 2)
3. Schulte-Hostedde, Millar and Hickling (2001:Table 1). Calculated as 12.71 g fat divided by 88.37 g dry mass.
4. Kaufman, Kaufman and Wiener. *Perognathus* data are means of species means for *Perognathus longimembris*, *P. formosus*, and *P. fallax*. *Dipodomys* data are means of species means for *Dipodomys merriami*, *D. microps*, and *D. agilis*.

Note: these values are listed on a dry matter basis and will be smaller on the basis of fresh meat. *Ambystoma texanum* males produce about 1.81 kcal for live weight of 7.71 g; nongravid *A. texanum* females, 1.42 kcal for live weight of 9.33 g (Finkler and Cullum 2002:Table 1).

1) the bone bed is a fluvial lag deposit

2) the bone bed is a raptor pellet midden

3) the bone bed is a latrine area for a terrestrial predator

If scenario 3 is selected, then there are two possibilities:

3A) the latrine area was used by a nonhuman predator

3B) the latrine area was used by human predators of small animals

In the following sections, I will evaluate arguments for and against these different scenarios. The discussion is simply a condensed version of what could be a much more detailed evaluation.

The Bone Bed As a Fluvial Lag Deposit

Some microvertebrates in the fossil record have been interpreted as having accumulated either in standing or running water. Some of the microfauna from the La Paloma mammoth find in Kenedy County may have originated in this way (Suhm 1980:95). Although most studies of bone behavior in fluvial environments have been done by taphonomists like Diane Gifford and Anna Behrensmeyer (1977), who are concerned mainly with larger animals, a few studies (Dodson 1971, Korth 1979, Wolff 1973, Brady 2005) have been done by paleontologists with taphonomic interests in the smaller vertebrates. Shipman (1981:22-41) and Brady (2005) provide useful summaries. At Berger Bluff, the hearth deposit is clearly not an in-channel assemblage, but occurs in a floodbasin facies, where the observations that seem most relevant are these:

1) *The bone is not streamworn.* Korth's experimental abrasion of small mammal bones in tumbling barrels shows exactly the location and kind of damage that ought to occur if bone is transported as bedload material (Korth 1979:262-265). See also Pinto Llona and Andrews (1999:Fig. 5). A few of the bone fragments show minor chemical rounding, but abrasion seems to be absent. Breakage of the bone is extensive, but is believed to be due to a combination of mastication, sediment compression, and excavation damage.

2) *Nothing is present to confine the deposit.* It does not lie in a basin or scour hole, but appears to represent a relatively thin, lens-like deposit that was originally left on a flat floodplain surface and was slightly dispersed both upward and downward after burial by very minor bioturbation. The northwest margin of the deposit laps onto the hard, baked surface of Feature 5.

3) *No other clasts with similar weight and density (chert or Goliad sandstone pebbles) were found among the bone, which was enclosed in fine-grained matrix.* If the bone bed is a lag deposit, where is the lithic bedload material? Near the top of the section, especially in stratum 2E, there are pockets and streamers of chert gravel that were probably lofted out of the channel onto the floodplain surface (see Chapter 4 discussion and photos), but these lack bone.

4) *The lipid analysis suggests soft tissue residues were deposited along with the bone.*

5) *Turtle shell and bone fragments from large animals are present in the ambient bone, but absent from the hearth deposit* (consistent with its interpretation as a coprolite accumulation).

6) *The hearth deposit includes both dense/compact and lightweight/flat bone fragments*, an observation that became apparent while rinsing off some of the cleaned bone. The mixture of these *hydrodynamically incompatible* elements argues against a lag deposit. Many small fragments are present that ought to have been winnowed out and removed even by a fairly weak current. Since these were obviously not removed when the bone bed was buried, the deposit may have been anchored by vegetation, matted together by vegetal digesta, or cemented by urine deposits.

The Bone Bed As a Raptor Pellet Midden

Background

Perhaps the most striking feature of the hearth deposit is that the animals are nearly all small. The largest animals are a juvenile and (presumably) an adult cottontail rabbit. The presumed adult remains are a tooth and a mandible fragment so small that it is difficult to tell much about the size of the rabbit. If the rabbit is an Eastern Cottontail, it might have weighed 1-2 kg or less. The only other potential larger animals are snakes, and there is uncertainty about the size of some of those, because vertebrae are not very good indicators of maximum snake size. Other than these possible exceptions, the animals are small, with mammals ranging from a least shrew at 4.0-7.5 g to woodrats at about 200-350 g. The fish are small fish (panfish or smaller) insofar as can be judged from the size of the vertebrae, the birds are small birds (perhaps small perching birds, sparrow-sized), the most identifiable snakes are small snakes, and the amphibians are fairly small as well.

Taken at face value, the small size of the animals in this microvertebrate bone bed might be considered diagnostic of a raptor pellet midden, and in fact, deposits like this, especially in caves and rockshelters, are usually interpreted as pellet middens. Raptors prefer small animals not just because their lifting capacity is limited, but also because the owls, at least, usually swallow their prey whole and do not extensively dismember them. Because raptors do not have teeth, they do not macerate their prey like terrestrial carnivores – instead, they swallow small animals whole, or larger animals in torn-off chunks, and most of the digestive work is done by very acidic gastric fluids. Digestion removes the meat and leaves a compacted mass of bone encased in hair or feathers, which is then regurgitated in the form of an oblong pellet at the roosting site. Usually about 35-49% of owl pellet weight is bone, the rest being hair (Moon 1940:Table II; Duke *et al*. 1975:Table 2); in contrast, only about 1.7-7.6% of hawk pellet weight is bone; (Duke *et al*. 1975:Table 2). For barn owls, each pellet contains, on average, 2.28 ± 1.05 prey individuals (Lyman, Power and Lyman 2003:10). In order to evaluate the hearth deposit as a potential pellet midden, a brief review of some basic facts about raptors is necessary.

Raptors include owls (Strigiformes, about 17 kinds in Texas) and diurnal birds of prey (Falconiformes, including caracaras, eagles, hawks, kites, falcons, about 34 kinds in Texas). These two orders differ in habits and physiology, so their pellet middens also differ. Owls are nocturnal birds of prey, prey chiefly on small night-foraging rodents which they tend to swallow whole, have less acidic gastric fluids, and create less extensive corrosion and breakage of bone in pellets [although Andrews (1990:32) says that bone breakage by owls has been underestimated]. Falconiforms, – especially hawks – are diurnal birds of prey, may prey on somewhat larger animals like rabbits as well, have more acidic stomach fluids, tend to tear their prey and cause more severe mechanical and

chemical damage to bone (Duke *et al*. 1975; Mayhew 1977). According to Dodson and Wexlar,

> Barn owls take 95% of their prey in the mouse size range; screech owls take 83% of their prey in this same size range… For great horned owls, mice form but 33% of their diet, while rabbit- and squirrel-sized items constitute 57% of the diet (Dodson and Wexlar 1979:282).

Hawks and owls are both opportunistic predators, the hawks specializing in daylight hunting, owls in nighttime hunting, with hawks taking, on average, somewhat larger prey (Jaksic 1983:Table 5).

All raptors have acid stomach fluids. For the barn owl (*Tyto alba*), the pH is about 4.0 before feeding and about 6.0 at pellet egestion (range, 1.9 to 6.2; Smith and Richmond 1972:180). For great horned owls (*Bubo virginianus*), the pH is 2.2 ± 0.7, red-tailed hawks (*Buteo jamaicensis*), 1.8 ± 0.8; for Swainson's hawk (*Buteo swainsoni*), 1.6 ± 0.2; for peregrine falcons (*Falco peregrinus*), 1.8 ± 0.2, for bald eagles (*Haliaeetus leucocephalus*), 1.3 ± 0.1 (Duke *et al*. 1975:Table 1). Immature raptors have more acid fluids and cause even greater bone loss, probably using the calcium for their own developing systems (Andrews 1990:31). Experiments suggest bone loss of about 65-82% at a "hawk" pH of 1.66 and about 25-37% at an "owl" pH of 2.35 (Cummings, Duke and Jegers 1976:Table 1).

Both breakage of the bones of prey animals and complete loss of some elements (due to digestion of the bone itself) occurs in the digestive process. Controlled feeding experiments with captive raptors have produced a large body of data. For the major skeletal elements recovered from owl pellets, about 85% are present (34% complete) in

great horned owl pellets; 82% present (72% complete) from barn owl pellets; and 72% present (18% complete) in screech owl pellets (Dodson and Wexlar 1979:Table 1). Andrews (1990:Table 2.3) lists completeness values of 27-63% for barn owl, 49-60% for long-eared owl, and 36-57% for short-eared owl. Data on hawks are much harder to find. Andrews (1990:Table 2.4) lists completeness values of about 21-42% for European kestrels, harriers and falcons, but the data collected by Hoffman (1988:Table 1) for red-tailed, rough-legged, and sparrow hawks suggest much lower completeness values; for example, recovery rates for mouse femurs were 6%, 1%, and 4% respectively, among the three hawk species. Hoffman's data confirm that for hawks, not just severe breakage but complete removal of bone elements is common.

Barn owls are notable among raptors for inflicting the least damage on bone. Figure 10.53 shows a raptor pellet collected on the upland right-of-way between Coleto Creek and Turkey Creek during the 1983 Flume 3 survey. The raptor is unidentified, but barn owl is a very plausible guess. The most notable aspects of the pellet contents are the completeness of the element inventory, the limited breakage, and the large number of epiphyseal caps from the long bones of juvenile animals. Either this owl was mostly targeting juveniles, or the pellet was cast during a season when many juveniles were dispersing. Figure 10.54 compares the maximum length of the bones or bone fragments in this pellet with those from the hearth deposit (this is the same curve as the one labeled "hearth deposit" in Fig. 10.22).

Bone fragments from hawk and other diurnal raptor pellets consists of sharp-pointed diaphysis fragments, elements with thinner areas corroded away by acids, and

rounded and corroded teeth with dissolved and powdered enamel (Mayhew 1977:26, Figs.2, 3).

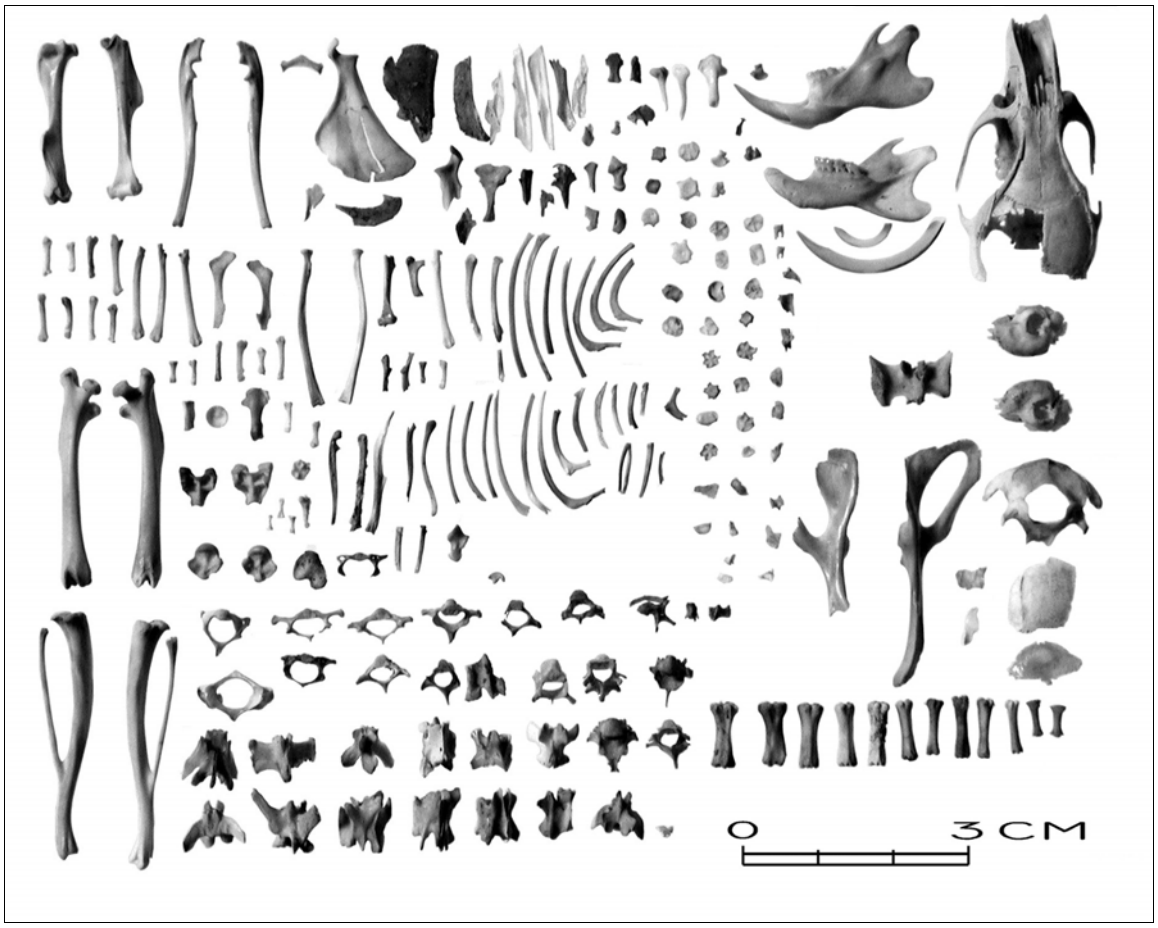


Figure 10.53. Contents of Raptor Pellet From Coleto Creek Reservoir. This is nearly all the bone in a pellet found on the upland surface in the Flume No. 3 survey. A domestic rat (*Rattus* sp.), at least one pocket mouse (*Chaetodipus/ Perognathus* sp.) and perhaps other individuals are present. Predator is unknown, but barn owl is plausible. Most elements are unbroken, even fragile ones like ribs. Element representation is fairly complete, and many are juveniles. Circular objects below and to left of mandibles are small epiphyseal caps from juvenile long bones. Not shown are a few *Chaetodipus/ Perognathus* bones and some insects. Compare with fragmented bone in Fig. 10.23.

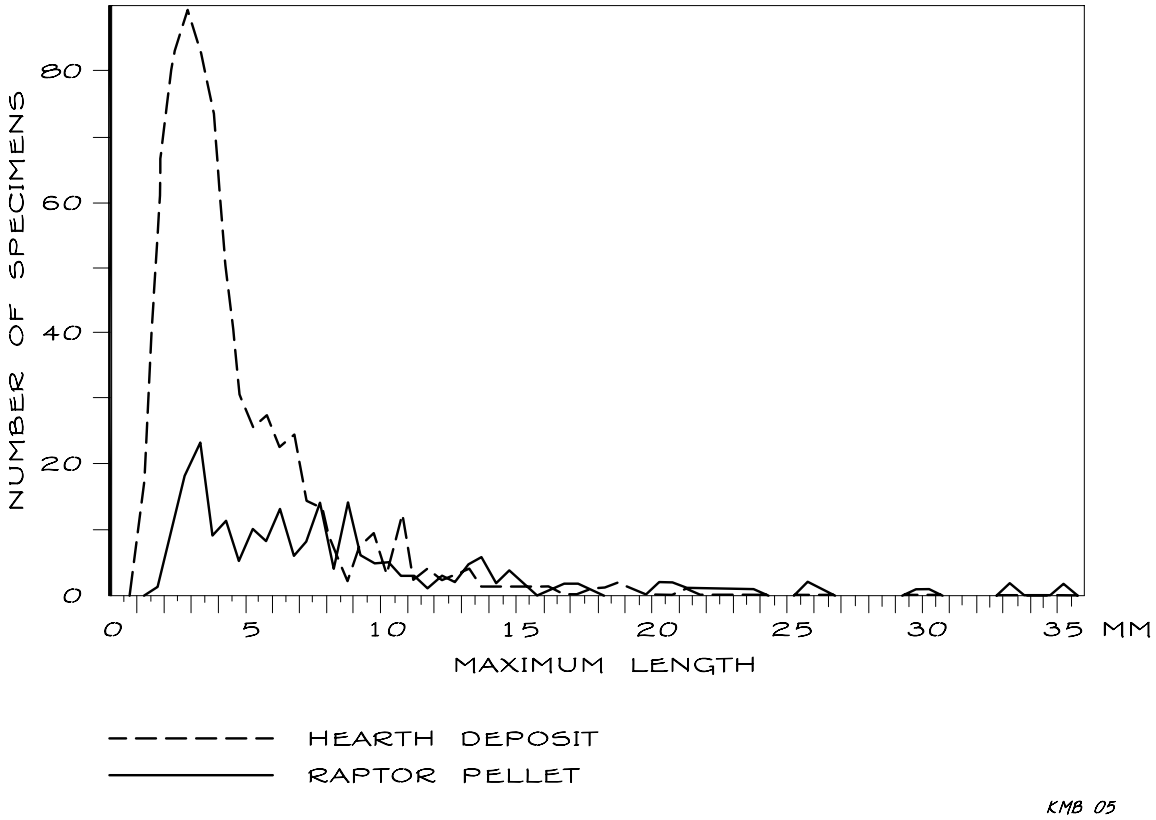


Figure 10.54. Comparing Fragment Size in the Hearth Deposit and a Raptor Pellet. The size distribution from the hearth deposit (copied from Fig. 10.22, measured to nearest tenth of a millimeter) is compared to the size distribution for bones and fragments from a raptor pellet, shown in the previous figure. The hearth deposit has fewer large items and many more fragments less than 5 mm in length, probably due to predator mastication.

Andrews summarizes the analytical problem thus:

> Many of the species of owl swallow their prey whole and so there is minimal breakage of postcranial elements. This contrasts with small mammalian carnivores, which usually chew their prey, and with the diurnal birds of prey, which tear their prey apart. A simple measure of breakage can thus be expected to differentiate these major groups of predator. This is attempted in this section, but it should be remembered that small mammal bone is extremely fragile and easily broken by agencies quite apart from the predator. As a result, fossil bone

> accumulations are usually so much more fragmentary than undamaged pellet assemblages that it is difficult to compare them (Andrews 1990:50).

Evaluation of the Hearth Deposit

The Feature 5 hearth deposit does not match the characteristics of a raptor pellet midden because:

1) *Fragmentation of the bone does not match that seen in raptor pellet middens.* In hawks, bone is either removed entirely or severely reduced by acid corrosion, but long bones are not usually snapped and crushed (see Andrews 1990:31, bottom). In Hoffman's captive feeding experiments, most mouse bones simply disappeared entirely from hawk pellets (Hoffman 1988:Table 1). Conversely, breakage in owl pellets is not as severe as that seen in the hearth deposit. In Dodson and Wexlar's experiments, on average about 44% of the elements they tabulated were complete; in Andrews's tabulation of the humerus, ulna, femur, and tibia in pellets of seven kinds of European owls, on average about 81% were complete. Compare this with the hearth deposit (Fig. 10.23), where nearly all the long bones are fragmentary, and the only elements that are complete are very small foot elements (unguals, phalanges, and so forth), vertebrae (caudal vertebrae may be complete; trunk vertebrae may have snapped zygopophyses) and occasional isolated fish or mammal teeth. Extensive fragmentation of the hearth deposit suggests mastication, which rules out all the avian predators – unless one is to argue that all the breakage is due to taphonomic or excavation damage.

2) *Essentially all the small mammals represented in the hearth deposit are nocturnal foragers*, which renders diurnal birds of prey as an unlikely predator. *Cryptotis, Dipodomys, Chaetodipus, Onychomys, Peromyscus, Neotoma*, and *Pitymys/Microtus* are

all nocturnal genera. *Scalopus* and *Geomys* are fossorial, with poor vision, and when they venture above ground, it is usually at night or in low-light conditions. *Sylvilagus* is most often crepuscular, but may be seen in the daytime.

3) *Salamanders, fish, and frogs or toads make up a significant portion of the hearth deposit*. Salamanders are rarely found in raptor pellets. A survey of amphibians and reptiles in raptor diets (Ross 1989) lists no examples of *Ambystoma texanum* as prey. The tiger salamander, *Ambystoma tigrinum*, is taken by burrowing owls, great horned owls and Swainson's hawks, but these instances are rare. Long-eared owls take *Ambystoma* sp. only in "trace" amounts (Marti 1976:Table 2). The Eastern screech owl, barred owl, and red-shouldered hawk have been found to take some other kinds of salamanders. With a few exceptions (common blackhawk, broad-winged hawk, red-shouldered hawk (Ross 1989:Table 2; Howell and Chapman 1998:Table 1); amphibians contribute almost no biomass to the diets of raptors in North America. Frogs (including bullfrogs and leopard frogs) and toads (including American toad) are taken by hawks and owls as well as loggerhead shrikes, but probably not in quantity except possibly by the last-named. Fish are taken by eagles, but they make up a major part of their diet, and normally appear in much greater numbers than are seen in the hearth deposit (cf. Bryan *et al*. 2005). In a survey of North American bald eagles, fish ranged from 6.1% to 90.1% of the diet; on the Texas coastal plain, they represent about 30% (Mabie, Merendino and Reid 1995:Tables 1, 2). In a golden eagle survey, fish represented only 0.4% (Olendorff 1976). Otherwise, fish appear only sporadically in hawk diets and almost never in owl diets. Of the fish remains in the hearth deposit, the larger vertebrae and fin spines are probably from panfish that might have been suitable raptor prey, but there are also very small vertebrae (little more than a millimeter in diameter, perhaps darter or shad-sized) from fish too

small for raptor prey. Unless these represent the stomach contents of some other animal consumed by a raptor, they are more likely to have been obtained by humans seining the creek.

Table 10.21 summarizes dietary data for raptors from South Texas (these are all pellet studies, except for the last, which lists observational data). No amphibians and only one instance of fish predation are listed for these South Texas raptors (although ferruginous pygmy owls, not listed here, do take narrowmouthed toads; Proudfoot, Beasom and Chavez-Ramirez 1999:4). The most frequent prey species are cotton rats, least shrews, fulvous harvest mice, rice rats, northern pygmy mice, and juvenile cottontails. Most of these prey species are likely to be found in open areas, although the following raptors have preferred habitat in riparian woods at Guadalupe Delta Wildlife Management Area: eastern screech owl, great horned owl, barred owl, white-tailed kite, bald eagle, sharp-shinned hawk, Cooper's hawk, and red-shouldered hawk (Texas Parks and Wildlife n. d.).

4) *Element representation does not match that seen in raptor pellet middens*. Table 10.22 is a rough approximation of the skeletal element frequencies for all analyzed small mammals from the hearth deposit combined. The information is extracted from Appendix 6 and includes many of the same kinds of assumptions used to compute the MNI totals. In compiling this list, two or more fragments in the same lot from the same kind of element were arbitrarily assumed to come from the same element. The list shows that isolated teeth and foot elements (phalanges, carpals, tarsals, metacarpals, metatarsals, astagali, calcanei) are much more abundant and pelvic elements and maxillae much less abundant than in the raptor samples studied by Andrews (1990:Figs. 3.2-3.4).

Table 10.21. South Texas Raptor Diets.

	Raptor and county	Barn owl, Colorado	Barn owl, Colorado	Barn owl, Calhoun	Barn owl, Aransas	Barn owl, Matagorda	Barn owl, San Patricio	Barn owl, Kleberg	Barn owl, Kleberg	Barn owl, Jim Wells	Barn owl, Cameron	Barn owl, Webb	Short-eared owl, Hidalgo	White-tailed kite, Jackson	Harris's hawk, Uvalde	Bald eagles, various	White-tailed hawk, Aransas, Refugio	Counts of occurrences
	Reference:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Prey Genus	Prey Species																	
Sigmodon	*hispidus*	X	X	X	X	X	X	X		X	X		X	X		X		12
Cryptotis	*parva*	X	X	X	X		X	X	X	X	X		X	X				11
Reithrodontomys	*fulvescens*	X	X	X	X	X	X	X		X	X	X						10
Oryzomys	*palustris*	X	X	X	X	X	X	X		X	X							9
Baiomys	*taylori*	X			X		X	X		X	X	X		X				8
Sylvilagus	*floridanus*	X	X				X	X	X		X	X					X	8
Peromyscus	*leucopus*	X	X				X	X			X		X				X	7
Chaetodipus	*hispidus*	X					X	X		X	X	X						6
Neotoma	*micropus*						X	X		X	X	X			X			6
Aves	(birds)	X	X			X	X*	X								X**		6
Mus	*musculus*	X	X					X		X		X	X					5
Scalopus	*aquaticus*	X	X		X				X									4
Notiosorex	*crawfordi*								X	X	X	X						4
Didelphis	*virginiana*	X	X						X							X		4
Perognathus	*flavus*							X	X		X							3
Onychomys	*leucogaster*							X		X		X						3
Geomys	*attwateri*	X			X												X	3
Perognathus	*merriami*									X		X						2
Geomys	*personatus*							X	X									2
Geomys	*bursarius*						X									X		2
Rattus	*rattus*	X	X															2
Liomys	*irroratus*										X		X					2
Sylvilagus	*florid./aububonii*									X					X			2
Lepus	*californicus*														X	X		2
Colinus	*virginianus*														X		X	2

(Table continued on next page)

(Table 10.21 continued from previous page)

Prey Genus	Prey Species	Raptor and county: Barn owl, Colorado	Barn owl, Colorado	Barn owl, Calhoun	Barn owl, Aransas	Barn owl, Matagorda	Barn owl, San Patricio	Barn owl, Kleberg	Barn owl, Kleberg	Barn owl, Jim Wells	Barn owl, Cameron	Barn owl, Webb	Short-eared owl, Hidalgo	White-tailed kite, Jackson	Harris's hawk, Uvalde	Bald eagles, various	White-tailed hawk, Aransas, Refugio	Counts of occurrences
	Reference:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Mimus	*polyglottos*														X		X	2
Blarina	*hylophaga*				X													1
Spermophilus	*mexicanus*														X			1
Geomys	*breviceps*		X															1
Sciurus	*niger*															X		1
Sylvilagus	*florid./aquaticus*															X		1
Dasypus	*novemcinctus*															X		1
Mephitis	*mephitis*															X		1
Sus	*scrofa*															X		1
Icteridae	(bird)												X					1
Callipela	*squamata*														X			1
Cyanocitta	*cristata*														X			1
Zenaida	*macroura*														X			1
Muscivora	*forficata*														X			1
Toxostoma	sp.														X			1
Sturnella	*magna*																X	1
Spizella	sp.									X								1
Serpentes	(snakes)		X															1
Pituophis	*sayi*																X	1
Thamnophis	*sirtalis*																X	1
Eumeces	*septrionalis*																X	1
Sceloporus	*undulatus*																X	1
Ophisaurus	*ventralis*																X	1
Fish																X**		1
Turtles																X**		1

(End of Table 10.21; references on next page)

References for Table 10.21

1 Baker (1986:Table 1)
2 Davis (1938)
3 Baker (1991:Table 1)
4 Baker (1991:Table 1)
5 Cameron (2003:Table 1)
6 Otteni (1971:Table 1)
7 Byrd (1982:Table 6)
8 Baker (1991:Table 1)
9 Raun (1960:Table 1)
10 Baker (1991:Table 1)
11 Goetze and Jimenez (1999:Table 1)
12 Hogan et al. (1996)
13 McKey and Fischer (1972)
14 Brannon (1980:Table 8)
15 Mabie, Merendino and Reid (1995:Table 1)
16 Stevenson and Meitzen (1946:202-303)

* See Otteni (1971:Appendix B) for complete list of bird species, too extensive to list here.

** See Mabie, Merendino and Reid (1995:Table 1) for complete list of birds, fish and turtles.

Terry (2004:Fig. 6) found that foot elements represented 44% of intact owl pellets, but were absent in broken-up pellets; she attributes the loss to decay and bioturbation.

5) *The hearth deposit is probably too small to represent a pellet midden*. Among the hundreds of raptor pellet studies that have been done over the last 50 years, I am aware of only one study where the researcher actually bothered to investigate the spatial distribution of fallen pellets at a roost. This is Terry's study of great horned owl pellets in Washington state. She found that bone concentration peaked at a distance of two meters from the roost tree, but some bone was found as far away as 4.5 m (Terry 2004:Fig. 4).

Table 10.22. Hearth Deposit: Element Representation for All Small Mammals Combined.

	MNE Totals			MNE Totals	
Cranial			**Hind limbs**		
skull	2		L femur	8	
L mandible	6		R femur	5	
R mandible	4		unspecified femur	10	
isolated teeth	86		L tibia	5	
Cranial total:		98	R tibia	3	
			unspecified tibia	4	
Appendicular			calcaneum	4	
			astragalus	3	
Forelimbs			second posterior phalanx	1	
scapulae	3		*Hind limb subtotal:*		43
L humerus	9				
R humerus	6		**Unspecified limb**		
unspecified humerus	8		metapodial	26	
L ulna	6		third phalanx	7	
R ulna	2		second phalanx	1	
unspecified ulna	1		first phalanx	2	
L radius	2		first/second phalanges	22	
R radius	2		tarsal/carpal	14	
unspecified radius	4		*Unspecified limb subtotal:*		72
metacarpal	2		*Appendicular total:*		196
carpal/metacarpal	8				
carpal	7		**Axial**		
third anterior phalanx	6		cervical vertebra	1	
second anterior phalanx	7		caudal vertebrae	30	
first anterior phalanx	8		unspecified vertebrae	13	
Forelimb subtotal:		81	*Vertebra subtotal:*		44
			ribs	12	
			Axial total:		56
			Pelvic region		
			pelvis	3	
			baculum	1	
			Pelvic total:		4

Even though the Berger Bluff hearth deposit was never completely excavated and little is known about its spatial limits, it is clear that the midden documented by Terry is far larger than the Berger Bluff hearth deposit. Unfortunately, I do not know how representative her study might be for raptors in general. Certainly pellets cast from a roost 5-10 m high ought to disperse over a fairly large area, especially when deflected by lower-hanging branches.

6) *There is no reason to expect a raptor pellet midden to be associated with a hearth or burned bone*. Feature 5 is not a burned raptor roost. It is clearly not a tree burn of any kind. The number of heat-altered fragments in the hearth deposit is very small, but they are nevertheless present, and the bone deposit extended right up to and onto the fired surface of the hearth. The association is as solid as any can be in the domain of archeology.

The Bone Bed As a Latrine Area for a Mammalian Predator

The hearth deposit seems to best match the characteristics of a latrine area for a mammalian predator (in a later section I will suggest the predator is probably human), for these reasons:

1) *Extensive breakage of the bone is interpreted as the result of mastication*.

2) *The presence of animal lipids in the hearth sediment suggests digestive system of the predator was not as efficient as raptor systems.*

3) *The perceived size of the bone bed is appropriate for a latrine area*, either for humans or for some small terrestrial predator such as a procyonid or mustelid.

4) *The taxonomic composition of the fauna seems consistent with the foraging range and abilities of a terrestrial predator*. The small birds present in the assemblage might be more difficult to catch for a terrestrial predator than for a raptor, but would be well within the capabilities of a human hunter-gatherer, or even a coyote.

Many mammalian predators use defined latrine areas, mark home ranges with scats, or bring food back to dens (Andrews and Evans 1983:290). Long-tailed weasels (*Mustela frenata*) and raccoons (*Procyon lotor*) are opportunistic riparian generalists with defined dens and latrine areas, and both seem in many respects to be good candidates for creators of the hearth deposit. Both species are nocturnal, but weasels may also forage in the daytime and have large home ranges which may encompass upland areas as well, making it a particularly good candidate. Other procyonids (ringtail) and mustelids (otter, mink) are probably less suitable candidates. Schmidly, describing weasels, says

> The bulk of their diet is composed of small mammals, including moles, shrews, ground squirrels, tree squirrels, flying squirrels, pocket gophers, woodrats, cotton rats, deer mice, harvest mice, and small cottontails. Occasionally, they will eat small birds, reptiles, amphibians, and insects…. Weasels often kill more than they need, in which case the surplus is stored for future use (Schmidly 2004:171).

Voles and grasshopper mice are also taken (Sheffield and Thomas 1997:5; Quick 1951). In the Midwest, *Microtus, Reithrodontomys, Peromyscus,* and *Sylvilagus* are important prey, especially in winter (Polderboer, Kuhn and Hendrickson 1941:Table 1). A long-tailed weasel den in Iowa is described as follows:

> The first den excavated was located in the weed patch. It was an old mole run that had been used by at least two weasels during the winter months. The nest was in an enlargement of one of the runs about six inches below the surface of the ground and about two feet from the entrance of the burrow. The nest cell was nine inches in diameter and had four burrows radiating from it. This nest chamber was filled with grasses packed in a layer-like formation. In the center of this mass was a nest hollow lined with patches of mouse and shrew fur. Beneath this layer of fur and at the sides of the nest were skins, various bones, and skulls of partially eaten mice and shrews. The presence of scats in the next mass indicated that the weasels had defecated in the nest…. A mass of scats was found packed into one of the radiating tunnels, and some mouse and shrew remains were found stored in two other tunnels (Polderboer, Kuhn and Hendrickson 1941:117).

Caching is also described by Muths (1998). In contrast to weasels, raccoons tend to den in trees and their scats may be left on or at the bases of trees (Noren 1941:Figs. 3, 5), especially in windfall gap areas. Page, Swihart and Kazacos (1998:183) report that "latrines were more often associated with substrates such as logs or stumps, increased numbers of understory trees, and higher average stem counts than random." The latrines are also foraging sites for granivorous rodents, birds, and other animals (including some animals eaten by raccoons) foraging for undigested seeds in decaying raccoon feces (Page, Swihart and Kazacos 2001). In North Dakota, 62% of foraging sites were in wetlands, 12% in wooded areas, and only 7% in upland grassland (Greenwood 1982:240). Weasel latrines tend to be located near dens (Quick 1951:283), which for weasels, are usually burrows. Errington (1936:406) describes a latrine as occupying "one square foot, some feet beyond the main entrance of the den." This is much smaller than otter (*Lutra canadensis*) latrines, which are described as 5-20 m in radius (Ben-David *et al*. 1998:2567). Weasels are small, swift animals with high metabolism (and correspondingly high defecation rates), adult males weighing only about 300-500 g, about the same body mass as a barn owl or Cooper's hawk. They have long, slender bodies adapted for hunting fossorial rodents in narrow tunnels and burrows. They may

occupy burrows (with enlarged chambers 3.5-5 cm in diameter) dug by moles or pocket gophers. Home ranges have been measured at 44-60 hectares for adult females and 120-241 hectares for males (Gehring and Swihart 2004). Raccoons are much larger animals (females, 4.6-8.6 kg, males 5.8-11.0 kg in San Patricio County; Gehrt and Fritzell 1999:21), and they eat a much greater proportion of plant foods and insects.

Very little information is available on bone in mustelid scats. Andrews and Evans (1983:302) looked at scats from the least weasel (*Mustela nivalis*), a smaller relative of the Texas long-tailed weasel, as well as the pine marten, another mustelid:

> The bones in these scats were generally too fragmentary for identification even to body parts…. The bones all show signs of digestion. The enamel on the vole molar prisms is etched and corroded along the salient angles and the dentine and cement are partly dissolved. The enamel on some of the rodent incisors is completely dissolved and the dentine deeply etched… the mandibles and maxillae have lost the outer surface of bone… The postcrania are generally broken, with rounded edges to the breaks and deeply corroded surfaces of the bone – where the surface has been penetrated the inside of the bone may be partly hollowed out (Andrews and Evans 1983:302).

Raccoons eat most of the species found in the hearth deposit, although not in the proportions recovered there. *Cryptotis parva, Scalopus aquaticus, Pitymys pinetorum, Peromyscus leucopus, P. maniculatus, Neotoma floridana*, tree squirrels, pocket mice, cotton rats, gophers, *Sylvilagus floridanus*, passerine birds, snakes, lizards (including *Sceloporus undulatus*), fish (centrarchids, cyprinids), frogs (*Rana* sp.) and other animal foods such as crawdads, turtle eggs, and snails have all been documented, although plant foods and insects make up a major part of the diet. Reptiles, amphibians, and fish (including minnows) are less important than might be expected in riparian habitats (Wood 1954).

Salamanders rarely appear in the diets of either weasels or raccoons, and documented cases are usually idiosyncratic examples of predation on single individuals (Sturges 1955). Greenwood (1981:757) found mandibles of *Ambystoma tigrinum* in 9% of raccoon scats in North Dakota. Unspecified salamanders have also been reported in Kentucky-Tennessee (Smith, Kennedy and Baumgardner 1987:Table 1), and Missouri (Noren 1941:76), but these are only one or two occurrences, unlike the kind of representation seen in the Feature 5 hearth deposit. Weasels and raccoons are opportunistic, but unless the smallmouth salamanders in the hearth deposit were ambushed during a migration or dispersal event, they seem unlikely prey. Upland species such as grasshopper and pocket mice and kangaroo rats are also rare or unreported in raccoon diets.

The diet of minks (*Mustela vison*) appears to be generally similar to that of long-tailed weasels, but some studies show greater use of fish, frogs, or birds (Arnold and Fritzell 1989:Table 1; Casson and Klimstra 1983:Table 1; Gilbert and Nancekivell 1982:Table 1; Korschgen 1958:Table 1; Waller 1962: Table 1). I have seen no mention of predation on salamanders.

Evaluation

The foregoing summary suggests that the hearth deposit fits the taphonomic and dietary profile of a terrestrial carnivore – such as a small mustelid – better than a raptor. The long-tailed weasel (*Mustela frenata*) and American mink (*Mustela vison*) are perhaps

the best candidates among the procyonids and small mustelids. However, there are a few mismatches between the profile and the archeological evidence:

1) If the extensive chemical digestion of bone documented by Andrews and Evans for the least weasel is also characteristic of the long-tailed weasel, *it does not match the masticated but mostly undigested bone in the hearth deposit.*

2) *The substantial numbers of salamanders, fish, frogs, and toads in the deposit are not characteristic of long-tailed weasel dietary profiles.*

3) *Voles are a major food item for weasels, but are scarce in the hearth deposit.*

4) *There is no reason to expect a mustelid latrine to be associated with a hearth or burned bone*.

The Bone Bed as a Human Latrine

The most parsimonious explanation for the microvertebrate bone bed adjacent to Feature 5 is probably that it is a human latrine area, and the most compelling arguments are probably the customary archeological ones of association and cultural modification. The most relevant questions seem to be these:

1) Is the bone deposit associated with other evidence of human activity?
2) Is the taphonomy of the deposit consistent with human digestion?

3) Does the taxonomic composition of the deposit correspond with dietary evidence from prehistoric hunter-gatherer sites?

Cultural Associations

Feature 5 is interpreted as a small hearth, not a tree burn or a burned woodrat house. The bone bed is adjacent at the same level, lapping slightly onto the baked surface. It seems clear that the latrine deposit was created after active use of the hearth had ceased, and the few bones in the deposit that show evidence of heat alteration were probably not burned in the hearth itself. I interpret the animal remains as likely having been cooked elsewhere (probably at some other site, or elsewhere on the floodplain), but the sparse evidence of heat alteration is significant because it suggests human involvement, regardless of where the cooking actually occurred.

Other than the bone, cultural debris found at the same level is sparse. Two microflakes or shatter fragments were recovered from the bone bed in fine-sieved loose matrix (N113 E98, 92.443-92.400 m, lot B-106). These appear to be cultural, not natural flakes or shovel retouch flakes (Fig. 10.55), although neither have bulbs of percussion. One (Fig. 10.55, B) is chert and may be an edge collapse flake, while the other looks like a quartzite thermal spall. Microflakes like these are often found in human coprolites from dry shelters (Stock 1983:Fig. 15, B), and some archeologists have suggested they were ingested when stone tool edges were rejuvenated by chipping with the teeth. Other than these items, there is no other cultural debris directly associated with the bone bed. A heavy percussion flake found 13.5 cm above the bone bed is presumably unrelated. It is not surprising that cultural debris is scarce – there would be no reason to expect much of

it in a latrine area, and debris density is very low everywhere in the bench deposits, anyway.

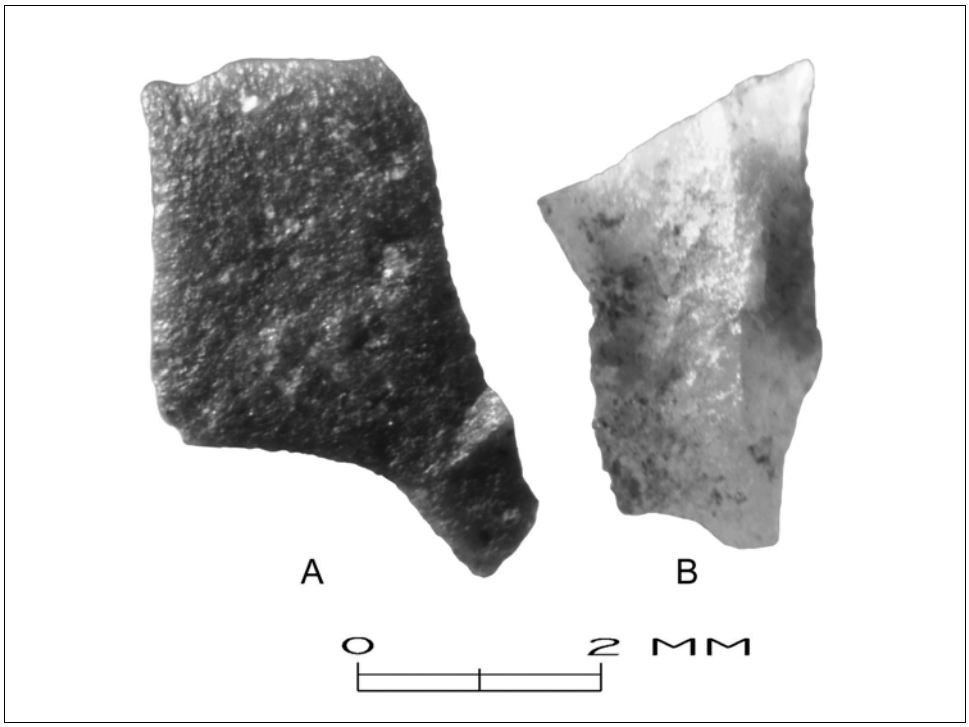


Figure 10.55. Microflakes From the Hearth Deposit. These very small specimens are the only lithic items recovered in direction association with the microvertebrate bone bed. Both are from N113 E98 (92.443-92.400 m, lot B-106). A is probably a quartzite thermal spall with very small patches of carbonate encrustation; B is a chert nicroflake; it lacks a bulb of percussion, but may be an edge-collapse flake. Neither shows any evidence of fluvial abrasion.

In the end, it is probably the evidence of limited heat alteration and of direct spatial association with the hearth that provide the strongest arguments for interpreting the bone bed as a human latrine. It is difficult to build any kind of convoluted scenario that would account for burning in a fluvial deposit, a raptor pellet midden, or a small carnivore latrine.

Human Digestion: What Kind of Evidence?

Unlike raptors, humans have teeth, and unlike other kinds of mammalian carnivores, humans have flat-topped molars well adapted for crushing bone. And unlike all other predators, humans usually (but not always) cook meat before eating it. More importantly, humans have *cuisine*, which means not only cooking meat, but eating it in combination with plant foods that might buffer the bone (both physically and chemically) against digestive damage (see Sutton and Reinhard 1995; Sutton 1993). Other carnivores (raccoons, for example) sometimes eat significant amounts of plant food, but usually not at the same time as animal foods, and not as part of a structured cuisine. These factors might be expected to contribute to some kind of human signature in digested small animal remains.

What kind of damage can be expected to show on bone that has passed through the human digestive tract? Information is surprisingly sparse. In a study by Crandall and Stahl (1995), a single short-tailed shrew (*Blarina brevicauda*) was skinned, eviscerated, boiled for two minutes, and swallowed without chewing by a human subject. The bone was recovered from the feces and studied. The study showed significant attrition. Some elements disappeared entirely, especially trunk vertebrae and phalanges. Teeth also disappeared or showed chemical alteration. Digestion removed the proximal end of a humerus and bent a tibia-fibula back upon itself (Crandall and Stahl 1995:Figs. 8, 10). The authors conclude that

> Nevertheless, skull breakage, maxillary tooth loss, mandibular breakage, and the high proportion of isolated teeth in the assemblage all compare at least minimally with small mammalian carnivores and Category 5 modification. Molar digestion is similar to mammalian carnivores in that a range of digestive states from intermediate to extreme damage were apparent (Crandall and Stahl 1995:795).

Unfortunately, this was not an entirely realistic experiment because the prey was not chewed, the cooking time was probably too short, and it is not clear from the report what else (besides the marker foods of corn and sesame seeds) was eaten along with the shrew. The most significant findings are probably that the bone recovered by Crandall and Stahl was probably much more chemically corroded than the bone from the Berger Bluff hearth deposit. Normal human gastric pH is probably around 1.5 to 1.6, about the same as that of hawks (it varies according to meal interval, age, and health) and is rather acidic. It is unfortunate that the experiment involved only one animal and did not replicate actual cuisine.

Human digestion of fish bone has also been studied experimentally by Jones (1986) and Butler and Schroeder (1998). The first study simply found that most of the bone disappeared, but the study by Butler and Schroeder is much more thorough and interesting. In their study, three tui chub (a cyprinid fish, about 66-85 mm long) were boiled for five minutes and swallowed with limited chewing. Fragments were recovered from feces passed through three sizes of fine mesh. Vertebrae (both trunk and caudal) survived best, but many cranial elements were lost; altogether, 84 elements out of the 315 originally present were recovered; of the 91 bone fragments recovered, 88 passed the 3.2 mm mesh and 29 passed the 1.6 mm mesh, so fragment size is quite comparable to that in the hearth deposit (Butler and Schroeder 1995:Table 1). Aside from fragmentation, the chief modifications produced were deformation of vertebrae (14 out of 19 specimens; Butler and Schroeder 1995:Table 6, Fig. 5). Deformation of the fresh, somewhat plastic vertebral centrum apparently occurs during or after mastication (I have not seen obvious plastic deformation on any of the Berger Bluff bone). Of the bones that survived, over

80% were at least two-thirds complete (Butler and Schroeder 1995:966). Butler and Schroeder also studied tui chub bones in 10 human coprolites from Hidden Cave, Nevada. These remains were also very small (70% passed the 3.2 mm screen), coming from fish estimated to average 57 mm in length. They were also much better preserved, with many elements having survivorship values over 50% (Butler and Schroeder 1995:Fig. 7). Surface pitting and edge rounding were common in some coprolites, uncommon in others. In general, the fish bone fragments from the Hidden Cave coprolites were better preserved than those recovered from the experimental ones, perhaps underscoring the importance of considering cuisine when doing this kind of experimental work.

The study of bone mastication among Bofi foragers done by Landt (2004) has considerable relevance, but is procedurally opposite to that of Crandall and Stahl, in that the bone was chewed but not digested. This review suggests that the experimental work that has been done on human digestion of bone is simply too limited to allow "agency diagnosis" of bone assemblages like those from Berger Bluff. Collections of human coprolites from dry shelters are probably the next best source of information. There are inevitable problems with coprolites, because archeologists will never know for sure what constituents have been eaten but not preserved, nor will we know for sure how cooking was done, but at least the problems of limited samples and unrealistic experimental design are lacking.

Comparative Evidence From Human Coprolites in Dry Regions

Almost all the documented coprolite assemblages (or analyzed mummies) come from Late Archaic sites in the Lower Pecos region of Texas, from other states in the

desert west, or from Mexico. Most come from dry shelters, although there are a few unsheltered latrines such as the Myoma Dunes and La Quinta sites in California (Wilke 1978; Sutton 1993). These have somewhat different prey animals (and undoubtedly different plants and cooking methods) from those at Berger Bluff, but are still very informative. The aggregate collections display a wide variety of subsistence and medicinal plants and small animals of all kinds. The intestines of the Skiles mummy (41 VV 656, 1150±70 RCYBP), for example, contained very small fish (two species of shiners, *Notropis* spp.), catfish, a small fossorial snake (*Tantilla* sp.), possible bat, an unidentified bird, and mice and gophers (*Peromyscus* and *Thomomys*; Turpin, Henneberg and Riskind 1986:307).

There is a great deal of cultural continuity in North American prehistory, and that makes this material relevant to the Berger Bluff research. This kind of material may be removed in space and time from the bench deposits at Berger Bluff, but it shows what kinds of animals were used, and if the bone fragments are studied carefully, they could show what kind of damage might be expected as a result of human digestion. Unfortunately, perhaps because most of the coprolite studies have been done by palynologists, the bone fragments are almost never studied beyond the initial attempt to identify the species, and sometimes even that is not done. The focus on most coprolite studies is on plants and pollen, and the bone has never been studied at the same level of taphonomic detail as that found in raptor pellets or carnivore scats. As a result, we have SEM photos and element counts of bones from owl pellets, but almost none from human coprolites. Nevertheless, the coprolites remain our best source of comparative information, and they show that all of the animals in the Berger Bluff hearth deposit were eaten by prehistoric hunter-gatherers -- at least, given the level of identification in most

of the studies. Sobolik (1993) has reviewed the recovery of small animals (excluding fish) in the United States. Her review shows that at the generic level and above, most of the taxa in the Berger Bluff hearth deposit have been recovered from coprolites somewhere in the US. Snakes (Colubrinae, Colubridae), *Sceloporus*, *Ambystoma*, *Rana*, various small birds, *Peromyscus*, *Onychomys*, *Microtus*, *Dipodomys*, *Neotoma*, and Geomyidae are all hearth deposit taxa represented by coprolites. Table 10.23 shows taxa recovered from coprolites in Texas and Tamaulipas, including three sites not reviewed by Sobolik. The only hearth deposit taxa that are not explicitly represented in the coprolite assemblages are the ?American toad (*Bufo americanus*), least shrew (*Cryptotis parva*), eastern mole (*Scalopus aquaticus*), and some snakes (?longnose, ?ringneck, brown or rough earth), undoubtedly missing simply because these are mostly species found in the eastern part of the state. It should also be mentioned that *Bufo* carries toxins that might make it unpalatable.

In some cases, reptile, lizard, and fish scales, otoliths, feathers, and bits of fur serve to identify some animals in coprolites, but none of these were found in the bench deposits. Otoliths might well have survived in the bench sediments, but none were found. The other items may well have been present at some time, but have since decayed. Animal bones recovered from known human coprolites vary widely in their completeness. At one end of the spectrum are the nearly complete *Perognathus* and partial *Baiomys taylori* skeletons reported from Tamaulipas by Marsh (1964). At the other end are highly fragmented remains that look very much like those in the hearth deposit (for example, see Sobolik 1988:Figs. 20, 22). Remarkably large pieces of bone are present in some coprolites.

Table 10.23. Taxa Recovered From Coprolites, Texas and Tamaulipas Sites.

Taxon	Common name	Hinds Cave	Baker Cave	Granado Cave	Portales or Romero's Cave	References
Identified at least to genus						
Aplodinotus grunniens	Freshwater drum	X				6
Ictalurus sp. or *Pylodictus* sp.	Catfish	X				6
Zenaidura sp.	Dove	X				6
Colinus viginianus	Northern bobwhite	X				6
Colubridae (cf. *Thamnophis sirtalis*)	cf. Garter snake	X				1
Colubridae (cf. *Masticophis flagellum*)	cf. Coachwhip	X				1
Chiroptera (cf. *Tadarida mexicana*)	Mexican free-tailed bat	X				1
Sceloporus (?) sp.	Rough-scaled lizard	X				6
Rana sp.	Frog	X				6
Citellus sp.	Ground squirrel	X				5, 6
Onychomys leucogaster	N. grasshopper mouse	X				6
Baiomys taylori	N. pygmy mouse				X	3
Reithrodontomys fulvescens	Fulvous harvest mouse				X	3
Peromyscus cf. *P. leucopus*	cf. White-tailed mouse		X			4
Peromyscus sp.	Deer mice	X	X			4, 6
cf. *Perognathus* sp.	cf. Pocket mouse				X	3
cf. *Dipodomys* sp.	cf. Kangaroo rat				X	3
Neotoma albigula	White-throated woodrat	X				6
Neotoma sp.	Woodrat	X	X	X		2, 4, 5,6
Sigmodon hispidus	Cotton rat	X	X			4, 5, 6
Lepus californicus	Black-tailed jackrabbit	X				6
Sylvilagus sp.	Cottontail	X	X	X		2, 4, 5, 6
Lepus sp.	Jackrabbit	X		X		2, 5
Ondatra zibethecus	Muskrat	X				5, 6
Procyon lotor	Raccoon	X				6
Urocyon cinereoargenteus	Gray fox	X				6
Odocoileus sp.	Deer	X				5

(Table continued on next page)

(Table 10.23 continued from previous page)

Identified to higher taxonomic levels						
Fish, small	Small fish	X				5, 6
Fish	Fish		X			4
Aves	Birds	X	X		X	1, 3, 4
Aves (wren-, dove/quail-, owl-sized)	Small-medium birds	X				6
Lacertilia	Lizards	X	X	X	X	2, 3, 4, 6
Serpentes	Snakes	X	X		X	3, 4, 5, 6
Rodentia	Rodents	X	X			1, 4
Rodentia, rat-sized	Rat-sized rodent	X				6
Rodentia, *Peromyscus*-sized	Deer mouse-sized rodent	X				6
O. leucogaster or *Reithrodontomys* sp.	Grasshopper or harvest mouse	X				6
Lagomorpha	Rabbits/hares	X	X			1, 4

1. Edwards (1990:Table 7)
2. Hunter (2001:Table 13.4)
3. Marsh (1964)
4. Sobolik (1988:143-44, Table 15)
5. Stock (1983:Table 10)
6. Williams-Dean (1978:Table 10)

Note: the currently recognized local ground squirrel is *Spermophilus mexicanus*, not *Citellus*. *Sylvilagus* cf. *S. audubonii* and *Neotoma* cf. *N. albigula* are also found in coprolites from Caldwell Cave (41 CU 1; Holloway 1985:Table 4).

Figure 10.56 shows a coprolite from Conejo Shelter with a large piece of unidentified bone from some small animal embedded in it. Figure 10.57 compares size grading of the Berger Bluff hearth deposit with bone fragments extracted from a single human coprolite excavated at Baker Cave (41 VV 213) in 1985. This coprolite (not one of the samples studied by Sobolik) was excavated from unit N5 E4 in stratum 2-16D (N5.06 E3.11, 98.63 m) and contained what appeared to be bone fragments created by smashing bone from some medium or large mammal (perhaps to produce bone grease?).

This is a source of bone that appears to be entirely lacking in the Berger Bluff bench deposits, but it illustrates part of the size distribution of bone fragments that may be found in human fecal remains. The fragments ranged in maximum length from 1.2-24.0 mm.

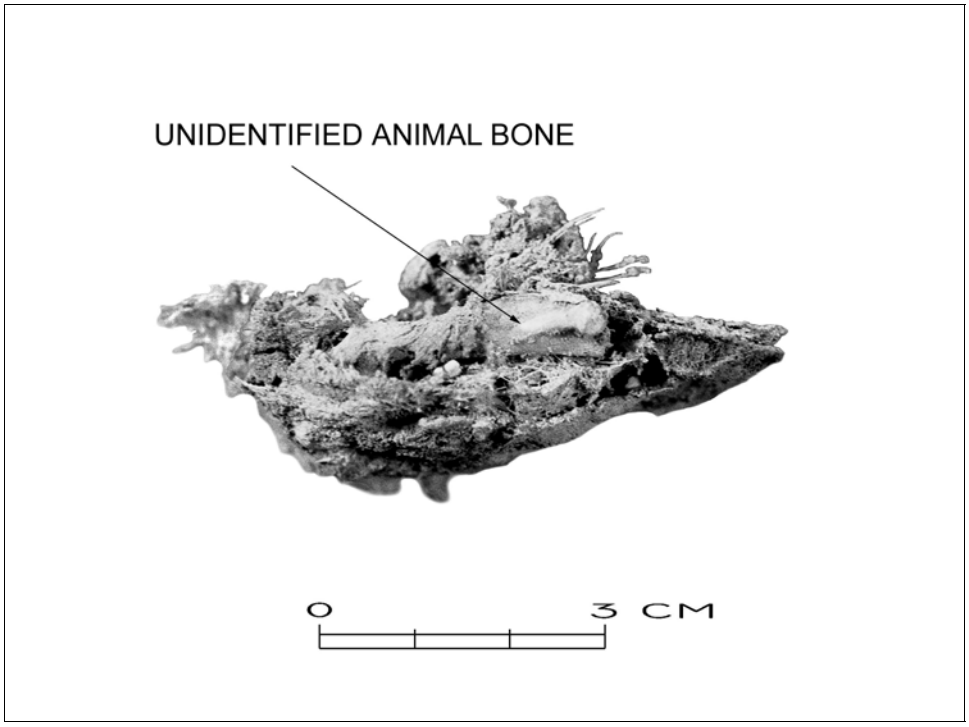


Figure 10.56. Human Coprolite From Conejo Shelter. Unidentified animal bone embedded in a coprolite from Conejo Shelter (41 VV 162), N90 W95, Lens 9, south end, 9.17; collected during the original field excavations in 1967 by Robert Alexander. This is specimen 30 from an unpublished isotope study by Jeff Huebner. It has a fibrous appearance because the occupants of the shelter had a high-fiber diet. Photo October 22, 1990.

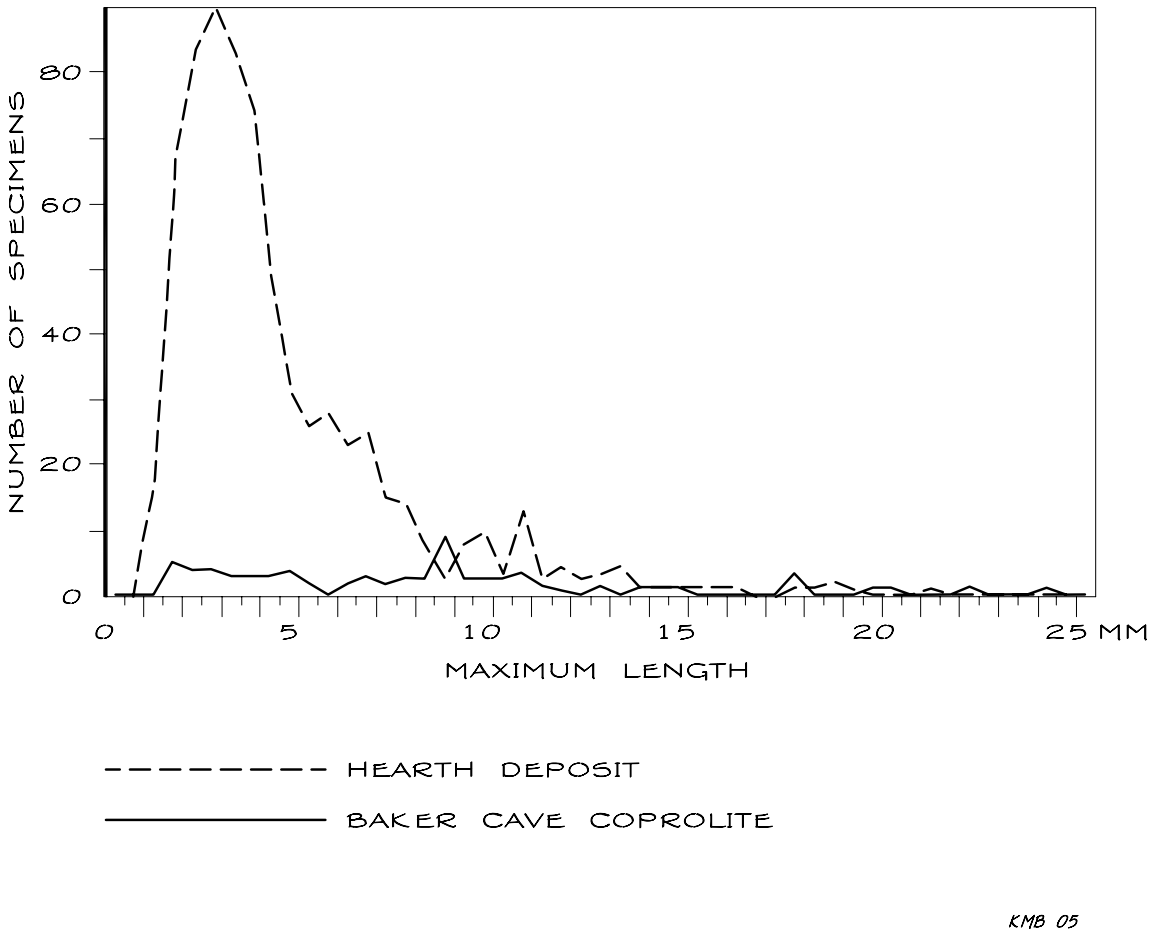


Figure 10.57. Comparing Fragment Size in the Hearth Deposit and a Coprolite From Baker Cave. The size distribution from the hearth deposit (copied from Fig. 10.22, measured to nearest tenth of a millimeter) is compared to size distribution for bone fragments in a human coprolite from Baker Cave (N5.06, E3.11, 98.63 m, stratum 2-16D). Bone fragments in the Baker Cave coprolite may have been produced by smashing bone from some large animal and have a much less clumped size distribution.

Figure 10.58 shows a very small long bone shaft fragment discovered in one of the unstudied lots of bone from the Berger Bluff hearth deposit. It has an unusual compression fracture in which splinters of bone (perhaps additional diaphysis fragments from the same long bone) have been rammed into the medullary cavity. This kind of

fragment compression is occasionally seen in raptor pellets, where it is produced by intense peristatltic activity in the raptor's alimentary tract. Whether it also occurs in human digestion is unknown, but it seems plausible.

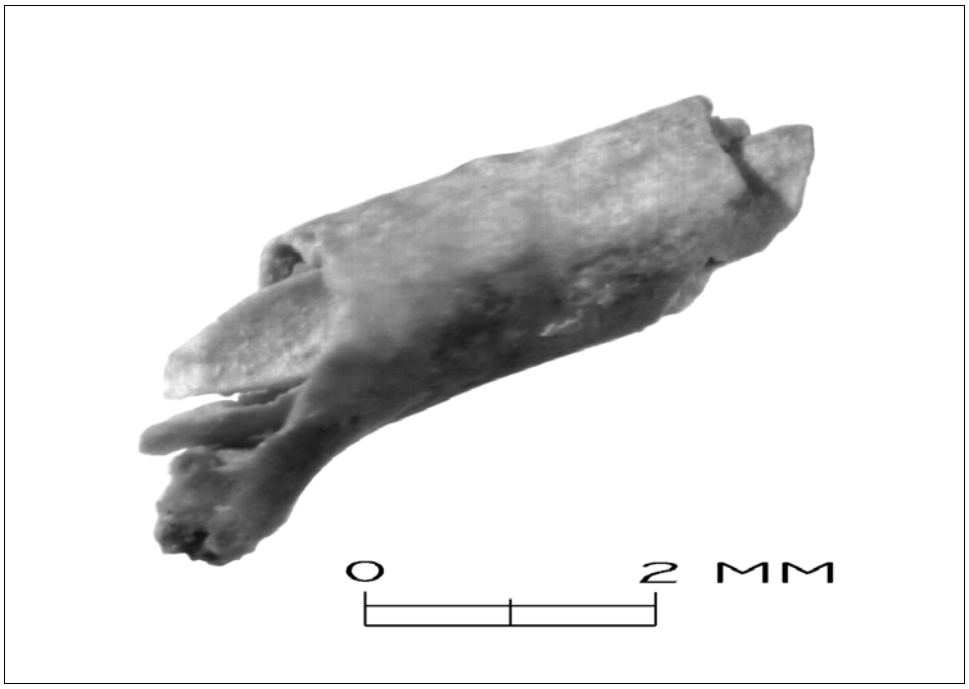


Figure 10.58. Hearth Deposit: Shaft Fragment With Compression Fracture. Unidentified very small long bone shaft fragment with splinters rammed into medullary cavity. N113 E98 (92.40-92.30 m, approximately upper 5 cm of level), lot B-107A.

Table 10.24 lists element representation for rodents in the Baker Cave coprolites studied by Sobolik. Unidentified rodents, *Peromyscus* and *Neotoma* are combined to create this listing (fish, lizards, and birds are omitted) condensed from Sobolik (1988:Table 15). The list shows that essentially all parts of the body are represented, confirming that rodents are eaten whole (although caudal and trunk vertebrae are not distinguished in the original table). Comparing this list (*rodents*) with Table 10.22 (*all small mammals*) shows that the two are much the same, except for a greater number of

unspecified limb elements and fewer axial elements in the hearth deposit. Figure 10.59 illustrates this similarity with pie charts.

Table 10.24. Element Representation in Baker Cave Coprolites.

Element		Count
Cranial		
cranial fragments		17
molars		25
incisors		9
mandible fragments		4
maxilla fragment		1
	Cranial total:	56
Forelimbs		
humerus fragments		6
radius fragments		4
scapula fragments		3
ulna fragment		1
	Forelimb total:	14
Hind limbs		
tibia fragments		8
femur fragments		5
tibia/fibula fragment		1
astragali		9
calcanei		2
	Hind limb total:	25
Unspecified limb		
phalanges		5
	Unspecified limb total:	5
Axial		
vertebrae		42
ribs		20
	Axial total:	62
Pelvic region		
os coxae		3
	Pelvic total:	3

Source: Sobolik (1988:Table 15). Note: counts for *Peromyscus*, *Neotoma*, and unidentified rodent are combined here.

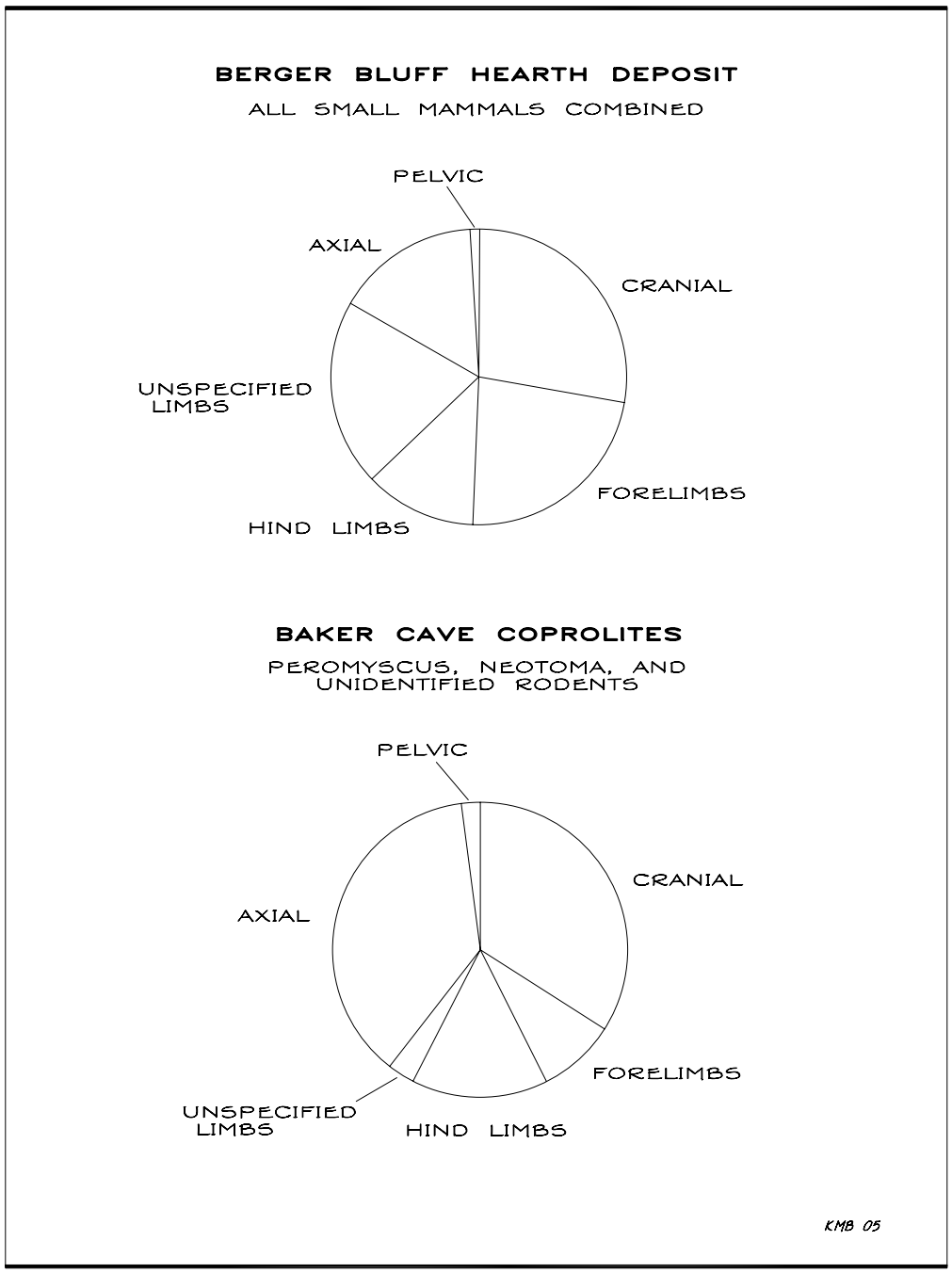


Figure 10.59. Element Representation Compared: Hearth Deposit and Baker Cave Coprolites. Top, data from Table 10.22. Bottom, data from Table 10.24, extracted from Sobolik (1988:Table 15). Note that the Baker Cave coprolite graphed in Fig. 10.57 is different from these.

Another important observation emerging from coprolite, mummy, and midden studies is that many of the fish remains are very small, suggesting mass capture (seining) of very small species (or juveniles of larger species), probably in shallows or backwaters. This was recognized as early as 1934, when Carl L. Hubbs identified possible minnow vertebrae in a coprolite from Fate Bell Shelter in Val Verde County (Jones 1935, Report No. 70-A, page 2). The small fish (shiners and a small catfish) found in the Skiles mummy have already been mentioned. The fish remains found by Williams-Dean (1978:197) and Stock (1983:110) in Hinds Cave coprolites are described as "small," although the only genera identified (*Aplodinotus* and *Ictalurus*) can grow to considerable size. Stock (1983:116) describes the remains as "tiny vertebrae and cranial fragments of small fish, including the catfish family, Ameuridae." Fish was the most common type of bone (vertebrae, ribs) found in Baker Cave coprolites by Sobolik (1988:144; Fig. 21), often accompanied by charcoal, although she says nothing about their size. Identification of fish scales from the coprolites by David J. Lee shows that most are from small taxa (Cypriniformes, Perciformes, Centrarchidae), presumably minnow-sized to panfish. Studies of the intestinal contents of the Spirit Cave mummy (9415 ± 25 RCYBP) showed large quantities of small fish bone (91.82% indeterminate Cyprinidae, 3.73% tui chub, 4.01% suckers, 0.43% redside or dace; Eiselt 1997:120), with vertebrae and head elements somewhat overrepresented. A live length of 3-7 cm is estimated for most of the fish (Eiselt 1997:131).

Very small fish remains have also been found in open sites, both in latrines and middens (Gobalet 1989). At Myoma Dunes,

> Many of the bones were burned, especially the fin spines and rays. This would indicate exposure to fire, either in drying and smoking or roasting, and 88% of the

> samples containing fish remains also included charcoal fragments…. Small fingerlings, as, for example those of Colorado River bonytail chub (*Gila elegans*) were consumed whole, as indicated by the pharyngeals and vertebrae recovered from the coprolites (Wilke 1978:82).

At the Rye Patch Reservoir project in Nevada,

> Two kinds of small fish were recovered from Rye Patch (*Rhinichthys* sp. and *Richardsonius* sp.), virtually all of them from Elko-age Feature 12 at Sandy Bank, which yielded 339 minnow bones from about 25% of the flotation sample recovered from the dark midden lens. In addition, 81 minnow bones were recovered in the field during screening…. Some of the recovered minnow bones were charred. Minnows were recognized as sometimes-important food items by the ethnographic Washo and Paiute…. They could be caught in quantity using baskets, a practice important both during droughts in isolated pools of a dying river, and in the winter through the ice…. Due to the nutritious nature of any fish, the small minnows are not regarded as culturally marginal food animals…. (Dansie 1987:141-142).

These examples show that prehistoric human consumption of minnow-sized fish and deposition of minnow-sized fish bone in latrine areas is by no means atypical, and it is consistent with the size range of the fish remains from Berger Bluff, in both the ambient and hearth deposit assemblages.

Comparative Evidence From Ethnographic Accounts

Ethnographic accounts of predation on small animals come mostly from northern Mexico and the desert West in the US. By the time serious ethnographic recording got underway in the second half of the 19th century, few residents of other areas retained precontact lifeways. These early ethnographers probably interviewed or observed mostly adult men, less often adult women, never children, and were far more interested in the taking of big game than in small animal collecting. Despite these obvious biases and

filters, scattered accounts of small animal predation can be found in the literature. These accounts make it clear that, particularly in arid areas, a wide variety of rodents, snakes, lizards, small birds and fish were taken. Rodents taken included not just larger species like prairie dogs, woodrats and ground squirrels, but smaller murids such as *Dipodomys* and *Peromyscus*.

Some of the most interesting accounts are the earliest ones by travelers and missionaries in the Spanish borderlands. Describing the 16th century "Chichimecs," Durán wrote:

> They hunted all day for rabbits, deer, hares, weasels, moles, wildcats, birds, snakes, lizards, mice, and they also collected locusts, worms, herbs, and roots. Their whole life was reduced to a quest for food. In order to kill a snake they spent an entire day crouching behind a bush, watching the snake at its lair as a cat will wait for a mouse (Durán 1964:11-12; note, in the original edition "topos" is used for moles and "ratones" is used for mice).

Describing the native inhabitants of Nuevo Leon in the middle 17th century, De León wrote:

> There is no bird of animal they do not eat, even unclean and poisonous ones, such as snakes, vipers, rats and other things, except the toad and the swift. They are, men as well as women, great fishermen. They fish with various methods, with the arrow, with nets, blinding the fish at night, and entering their caves to seek them out. They roast them with tripe, often after two days… (Brown 1988:9).

Describing Baja California in 1761, Jacob Baegert wrote:

> The Indians also eat snakes, lizards, night owls, bats and pieces of meat which they scratch from animal skins… It is very common that the Indians eat all kind and species of mice, and catching them is such sport that they customarily spend weeks at it. When they go hunting, those of them who speak some Spanish say *ruta* and *raten* (mice and rats), and *voi ratenar*, I go mice hunting; just as those Indians when they go fishing say, *vado piscari*, I go fishing.

> Spiders, even large ones, toads and similar vermin, they either kill with their hands or take them away with their bare hands when they have already been killed (Baegert 1982:222).

Also writing in the middle 18th century (1755-1767), Joseph Och wrote:

> They catch snakes…. Only if they are excessively hungry do they skin them, wrap them around a stick, roast them in the fire, and eat them with great relish, in the manner of eating an eel.
>
> This voracity incites them also to gulp down unseemly things such as rats of great size, larger than two fists; snakes of various lengths and thicknesses, as well as finger-long grasshoppers (Och 1965:131-132; 179).

Speaking of the "Indians of the province of Texas," in 1767-68, Fray Gaspar José de Solís wrote:

> In the woods they live on horses, mules, mares, deer, since there are many, bison which abound, bear, *berrendos*, wild boar, rabbits, hares, dormice, and other quadrupeds, with snakes, vipers, wild turkeys, geese, ducks, hens, partridges, cranes, quail and other kinds of birds that are on the beach or on the banks and margins of the rivers, with fish of all kinds, which abound (Kress 1931:43).

The following account of a fire drive by Ignaz Pfefferkorn is translated from the 1794 original:

> This thick brush is infested with large numbers of rats and mice which the Sonorans sometimes hunt. Twenty or thirty and sometimes more Sonorans assemble and surround a given circle of brush. They start fires, setting the dry brush ablaze in a circle, and the animals hidden therein are forced to take flight. As the fire advances, the animals retreat more and more to the center and the Indians in turn close the circle on them. In this manner the hunt is continued, until finally a large number of rats and mice is driven together into the center. Of these, the heat has already killed some and burned others; the rest are killed by the Indians with clubs. Then the distribution is made. Each Indian fastens to a string by their tails the mice which have fallen to his share. He hangs this string over his shoulder like a bandoleer (Pfefferkorn 1949:198-199).

Writing in 1799, José Cortés wrote

> From the tenderest age they are schooled in this vital activity. When they are boys, the hunting of prairie dogs, ferrets, squirrels, hares, rabbits, badgers, and mice is reserved for them (Cortés 1989:68).

Almost a century later, Eugene Trippel described the diet of the Yuma:

> Moles, gophers, chipmunks, woodrats, jack and cottontail rabbits, small birds, quail, wild ducks and geese, and land tortoises, diversify the bill of fare (Trippel 1889:575).

This much later account comes from the Yaqui, 1939-1945:

> My poor sister-in-law was a good and patient woman. She just went looking for rats and cactus when there was nothing else to eat.
>
> Big rats built nests up high in mesquite trees. She had to walk three or four miles to find any rats because they were all gone around Torim village, since the poor Yaqui families hunted out every rat nest near the pueblo. When the Yaquis have plenty of corn and beans and meat to eat, rats move back closer to the village. You can tell how hungry the people of Torim are by how close to the village rats can be found. The name of our village, Torim, means rats; maybe people here have always had to eat rats.
>
> Anastasia could get two or three dozen rats on a good day, cooking them in an olla with corn or wheat (Moisés, Kelley and Holden 1971:179-180).

This account is interesting because it is one of the few accounts that mentions women procuring small animals, and because it shows that by the 1940s, rats were no longer highly esteemed as a food source. For the Panamint,

> Their animal food consists principally of jack-rabbits, cotton-tail rabbits, and quails, occasionally mountain sheep or deer, and sometimes wood rats, kangaroo rats, white-footed mice, and a large lizard known as the chuckawara (Colville 1892:352).

Delfina Cuero, a Diegueno informant, recounted

> We used to eat rats, mice, lizards, and some snakes, but I don't remember what kind. We roasted them. The little things were pounded on a rock. Bones and all and then stewed (Cuero1970:32-33).

An early account by Palmer of the Paiute says

> I saw them collect grasshoppers, land turtles, lizards, snakes, mice, ratts [*sic*] and rabbits, swifts and horned toned [*sic*, horned toads] and without taking off their hides or extracting their entrails threw them on the fire cooked them a little, with their fingers took them out and devoured them… (Heizer 1954:7).

Powell wrote,

> Lizards are used for food in seasons of scarcity. They are killed by throwing stones or clubs at them, or are shot with arrows. Many are caught with hooks which are used to pull them from the crevices in the rocks.
>
> The region inhabited by the Utes swarms with these reptiles an in warm seasons they may be caught in great numbers. Sometimes they are collected for winter use, and for this purpose they are arranged in long strings by hooking the tail of one into the mouth of another. Then the strings are hung up on the branches of trees to dry, and when thoroughly dried they are laid away in this form or ground with mealing stones and preserved as flour.
>
> Horned toads (species *rhynomosa* [sic; *Phrynosoma* spp.]) are sometimes used in the same way but only in cases of great want… Fowler and Fowler 1971:14).

Among the Northern Ute,

> Only the Uintahs ate field mice. A hunter would sit where he saw the trail of the mice and catch them when they came by. Mice were cooked in hot coals, and when done, were skinned and the entrails were removed.
>
> The Uintahs shot rats with bow and arrow. The entrails were removed before roasting the rats in the coals. Prairie dogs were treated in the same way (Smith 1974:49).

The following comes from Frank Buckelew's account of captivity by the Lipan Indians in 1866:

> We came to a place where rats had made large mounds of sand among the prickly pear. The Indians spent some time here and killed enough rats to have a real feast. Rats seemed to be a very choice meat among the Lipans. They would roast them whole, and when taken from the fire the skin and fur were burnt to a crisp, this was peeled off and the flesh eaten. The intestines were dried up in a hard lump and this was thrown away. I was hungry enough to eat the roasted rats. The Indians seemed to think they were a rare treat (Dennis and Dennis 1925:128).

From the reference to "mounds of sand," it seems likely these were kangaroo rats, probably *Dipodomys ordii*, *D. merriami*, or less likely *D. compactus*.

The Northern Paiute used deadfalls to trap prairie dogs, gophers, or ground squirrels (the same term is used for all), whitetail antelope ground squirrels (*Amnospermophilus leucurus*), western gray squirrels (*Sciurus griseus*), desert woodrats (*Neotoma lepida*) and bushy-tailed woodrats (*N. cinerea*), golden-mantled ground squirrels (*Spermophilus lateralis*), Townsend's chipmunk (*Eutamias townsendii*), desert kangaroo rats (*Dipodomys deserti*), Ord's kangaroo rats (*D. ordii*), deer mice (*Peromyscus maniculatus*) or western harvest mice (*Reithrodontomys megalotis*), and pinyon mice (*Peromyscus truei*; Fowler 1989:23-24). The Kaiparowits Southern Paiute hunted marmots, unspecified squirrels, chipmunks, gophers, and unspecified rats (Kelly 1964:157). The Walapai hunted rats (evidently woodrats), kangaroo rats, chuckwallas, snakes, and lizards, as well as "practically every available bird" (McKennan 1935:64). The Tepehuan of Chichuahua trap gophers, moles, woodrats, and unspecified mice (Pennington 1969:124-125). The Pima Bajo killed gophers, moles, "bushy-tailed rats" (woodrats, presumably), tree and ground squirrels (Pennington 1980:201-202). Northern Pimans (the Papago and their neighbors along the Gila River) hunted cotton rats

(*Sigmodon arizonae*), woodrats (*Neotoma albigula*), jackrabbits, round-tailed ground squirrels (*Spermophilus tereticaudus*), and Harris's antelope squirrel (*Ammospermophilus harrisii*; Rea 1998:Table 4.1). Cotton rats were prized above all:

> People eat those. They live in that *no'oshkal*, breed in there. Not fat. But they got more meat in there. Put a stick through and put them over the fire. Don't skin them. Then just peel them off after. Roast them again. Then this time they get brown. One or two is enough. They do that when they go out hunting and burn the brush (Rea 1998:177).

The above accounts are just a very small sample of some of the recorded ethnographic literature. They show that lizards and mouse-sized rodents (perhaps in the 20-40 g size range) were hunted or trapped along with somewhat larger kangaroo rats (generally in the 40-70 g size range) and the larger woodrats, cotton rats, and gophers (generally about 150-350 g). In desert areas, granivorous rodents probably represented a major portion of the available animal biomass. Hunting and trapping was probably most often done by individuals or small groups (for example, groups of boys). The fire drives described by Pfefferkorn and Rea's informant are presumably somewhat less common "mass capture" events. A more efficient mass capture technique was to let the snakes eat the rodents, and then eat the snakes, which probably accounts for how often snakes appear as food items in these borderland accounts. Some small animals are seldom or never mentioned in dietary accounts – notably shrews, salamanders, frogs, and toads (other than horned toads, which are really iguanid lizards anyway). In most cases these are neither confirmed or denied as food sources, so we can only say that they were not recorded. The ethnographies do not prove they were not eaten.

Bias Against Small Animals by Archeologists and Ethnographers

Given that the bones of all these small animals appear in prehistoric human coprolites, that the available ethnographies from the same regions clearly describe their use as food sources, and there is artifactual evidence of trapping, collecting, evisceration, cooking and mealing of small animals, one would think that the issue of human predation on small animals had been settled long ago. What about artifactual evidence?

Figure 10.60 illustrates some gear – found in dry shelters in the Lake Amistad region – suitable for procuring small animals. Shown are a generalized digging stick, a probable deadfall trigger stick, and part of a scissors snare. Only the scissors snare (C) is dated (at 2440 RCYBP), but the other two items are probably of equal or lesser vintage. Probably only the digging stick (A) was in use at Berger Bluff, but this assemblage illustrates that this Late Archaic technology exists in the dry shelters of the region, even though most of it has been left for pothunters to recover. Deadfalls probably would not have been used at Berger Bluff because the local Goliad Sandstone bedrock does not break up into large, flat, durable slabs.

In a sample of stone tools from Hinds Cave examined for organic residue, rodent hair was found on nine, rabbit hair on three, and deer hair on only two (Sobolik 1996:Table 1; see also Yohe, Newman and Schneider 1991), suggesting these tools were mostly used to process rodents.

Despite the overwhelming array of evidence I have presented above, there has always been considerable resistance by archeologists to acceptance of small animals as

food items. Most of the resistance is directed at snakes, lizards, amphibians, bats, and especially rodents. Small birds, fish, and turtles seem to be less controversial. Rodent remains are usually dismissed as "intrusive," oftentimes even when they belong to non-burrowing species (Morlan 1994:135).

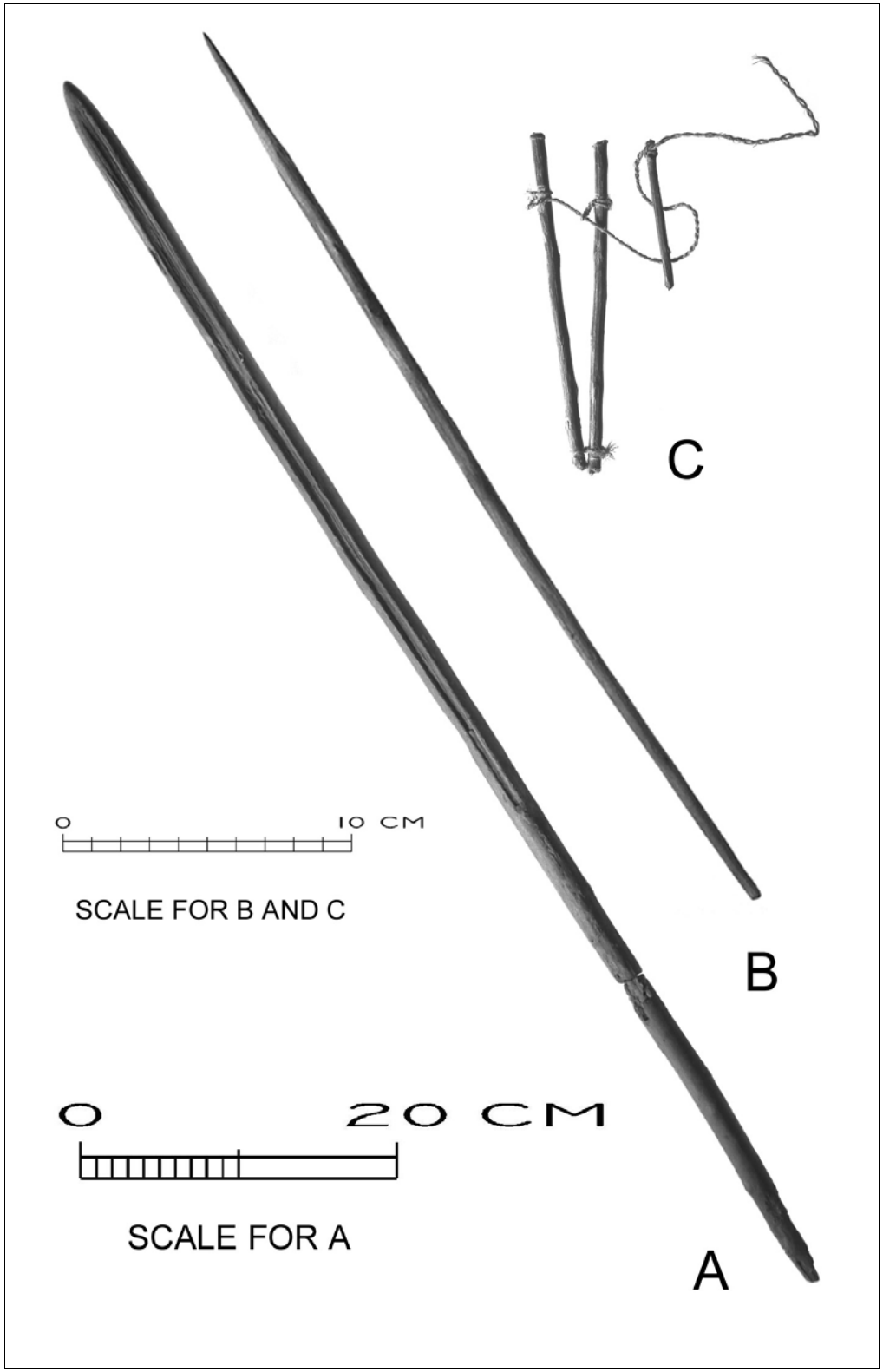
"Intrusive" is a code word meaning that the zooarcheologist can then abandon any further analytical responsibility. Richard Morlan observes,

> It seems fair to say that these animals burrow to live, not to die. In this perspective the discovery of a burrower's bones in an archaeological site can be considered a failure in the burrowing strategy…. The main message is that any rodent that can intrude itself into an archaeological site can probably extrude itself as well. Rodent bones occur in sites not because of rodent activities but because their activities are interrupted by some other agency, usually their predators (Morlan 1994:135, 139).

Archeologists who are convinced that rodents are always intrusive should demonstrate it by digging control pits outside of site boundaries and showing that rodent bone densities are just as high outside the site as inside.

Many of the animals found in the Berger Bluff hearth deposit are fossorial and/or nocturnal foragers. Species like these are ideal prey for diurnal foraging humans, because they are confined to burrows during the day and can be dug out with a digging stick like the one shown in Fig. 10.60. Often there are indications, like fresh dirt mounds, showing whether a burrow is occupied. Strictly fossorial species, like the eastern mole and pocket gophers, are not fast runners. Essentially blind when dug out and exposed to bright daylight, they cannot escape. Cursorial nocturnal foragers, like kangaroo rats and pocket mice, are fast runners but usually have large eyes adapted to functioning in very low light levels and are ill-adapted to navigation when suddenly thrust into bright daylight.

Figure 10.60 (*following page*). Prehistoric Small-Animal Procurement Gear From the Lower Pecos. Found in dry shelters, these are examples of artifacts that could have been used for small animal procurement. A is a wooden digging stick (distal end at top) that was mostly used for plant collection but could also be used to excavate occupied animal burrows (wooden artifact recording project, specimen 12-1). It comes from 41 VV 66 in the Lake Amistad area. B is a possible deadfall trigger stick from an unrecorded site in the Lake Amistad area (specimen 2-11). C is part of a scissors snare (specimen M) from Baker Cave (41 VV 213), Greer excavations, Square 20, Zone 7 (=9), Feature 117, dating to 2440 RCYBP. Note that items B and C are shown at about twice the scale of the digging stick. Of the items shown here, probably only the digging stick was used at Berger Bluff, but this illustration is intended to illustrate that there is artifactual as well as coprolite and midden evidence of small animal use.


C
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B
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A

Traps or snares could be used to capture some of these animals, but for most of them, a digging stick and a dog are all the technology needed. Snares for birds and seines for fish might be needed. Reptiles and amphibians (particularly the salamanders) can be caught in pitfalls, leading one to wonder if the two small pits (Feature 6 and Feature 7) could possibly have functioned as amphibian pitfalls. Present-day herptetologists conducting amphibian censuses usually find that pitfalls are the most effective capture technique. Feature 6 originated in stratum 2A and clearly predates the microvertebrate bone bed, but the surface of origin for Feature 7 is somewhat ambiguous (Fig. 4.39). The notion that it is contemporary with Feature 5 and the hearth deposit cannot be ruled out. Whyte (1991:170) found that small mammals, frogs, and toads could escape from pits 40 cm deep unless the walls were moist or the pit was water-filled. Rodents, especially heteromyids, should be able to escape from small pits like Feature 6 and Feature 7.

The reptiles and amphibians found in the hearth deposit are all ectotherms. Animals like these are sluggish when warming up after a cool night. Smallmouth salamanders, toads, ringnecked snakes, or longnose snakes might be caught emerging from burrows or under logs rolled aside during early morning foraging trips by gathering parties, as well as caught in pitfalls.

Mary Stiner has already expressed my view of these animals as resources in a section she calls “Hunting by Gathering,”

> The use of plants and that of small animals have much in common tactically because these resources are stationary gatherable particles, often scattered in time and space. These characteristics generally set plants and small prey apart from large game.

> Small prey may be considered sessile in habit either because they are truly immobile (as are plants), or because their territories are so small that the effect is one of immobility from the human point of view. Small prey may also require different, sometimes incompatible, search and procurement tactics from what is typical of large game hunting. Small animals are protein-rich, sometimes fat-rich, and represent potential sources of limiting nutrients that humans must consume regularly. Because most kinds of small prey are easily gathered, they are accessible to a wider variety of persons (ages and sexes) in social groups, and obtaining them is less likely to conflict with the demands of child care (Stiner 1994:158).

Small animals have some other properties making them useful food sources for hunter-gatherers. As Stiner indicates, they may be encountered while foraging for plant foods, so in optimal foraging terms, there is no additional "search time" cost, and their sessile habits mean that "pursuit time" is relatively minimal as well. For small mammals in particular, the edible meat percentage is quite high. Stahl (1982:823) estimates edible meat percentages at about 67-76% for small mammals he sampled (for species found at Berger Bluff that he studied, the percentage is even higher, about 85%). Many rodents have seasonal lipid cycles, storing up fat for the winter season (Fleharty, Krause and Stinnett 1973:Fig. 5). As a result, rodents taken in late fall or early winter would have particularly high fat content.

Evaluation: The Bone Bed As a Human Latrine

Reviewing the criteria presented earlier, we can conclude that the extensive mechanical breakage and limited evidence of chemical rounding seen on the hearth deposit bone is probably consistent with an interpretation of human digestion, but a definitive taphonomic evaluation is hampered by the lack of detailed studies of bone known to have passed through the human digestive tract. The few experimental studies

that have been done seem to indicate more severe bone loss, chemical damage, and deformation than is seen in the hearth deposit, but these studies have generally lacked a realistic design (for example, limited or no chewing of the bone). A "cuisine-based" approach in which plant foods buffer the animal foods needs to be tried, and experimental bones should be chewed, not eschewed. Until better and more realistic experiments are done, I regard the taphonomic profile for human-digested bone as ambiguous. Likewise, a significant sample of bone has been extracted from known human coprolites at various sites in the Trans-Pecos and Lower Pecos regions of Texas, but studies of the bone have never extended beyond identified species and elements, so here again the opportunity to define what digested bone looks like has been deferred.

On the other hand, it is possible to say with some certainty that both the ethnographic and coprolite records of human diet in the region are consistent with the taxonomic composition of the hearth deposit. To be sure, these records are well removed both in space and time from Berger Bluff, but we can say that elsewhere, in later prehistory, native populations were eating similar kinds of animal foods. Salamanders appear rarely in coprolite records, and I find no explicit mention of them as human food in any of the ethnographies -- but this could well be a case of inadequate documentation.

The strongest evidence for human agency remains the clear spatial association of the bone bed with the hearth, Feature 5. I can envision no plausible scenario that would link a mustelid latrine or a raptor pellet midden to a restricted area of fire-building on a flat floodplain surface, but it is easy to imagine the trampled and vegetation-cleared area around an abandoned hearth being selected as a preferred human latrine at a site that was visited only sporadically during the course of foraging trips.

SPECIES ACCOUNTS

If only one or two items are present, provenience is listed; if more than one or two are present, it is omitted but can be looked up in Appendix 6.

Lepisosteus sp. (unknown species of gar; Fig. 10.61)
Ambient fauna
1 ganoid scale

A single very small ganoid from some unknown species of gar was discovered in an as yet unstudied lot of bone from N109 E96 (93.08-93.00 m, bulk matrix, coarse fraction). Because this item adds a new taxon to the species list from the bench deposits, I report it here, even though the rest of the lot remains unstudied. Gars have scales in a variety of sizes covering their bodies, and this one is far smaller than most of the hundreds of gar scales recovered from the Late Holocene blufftop midden. It could belong to any of three species of gar (alligator, longnose, or spotted) found in the region. Flynn (1983) identified some of the gar from the blufftop midden as *Lepisosteus osseus*, but I am not sure of the basis for the identification. Gar usually imply fairly deep pools of water, consistent with the hydrological reconstruction presented in Chapter 4. They can also grow to be very large individuals, but the size of this one is unknown.

Fish, unidentified, small to medium-sized (Figs. 10.1, 10.26; 10.30, A, E; 10.46, I, K; 10.51, A-E; 10.62 to 10.65)

Element	Ambient bone NISP	Hearth deposit NISP
mandible	1	
teeth	2	2
vertebrae	1	27
dorsal fin spine		6
pectoral fin spine		1
unidentified fin spine	6	1
unidentified fragments	2	12

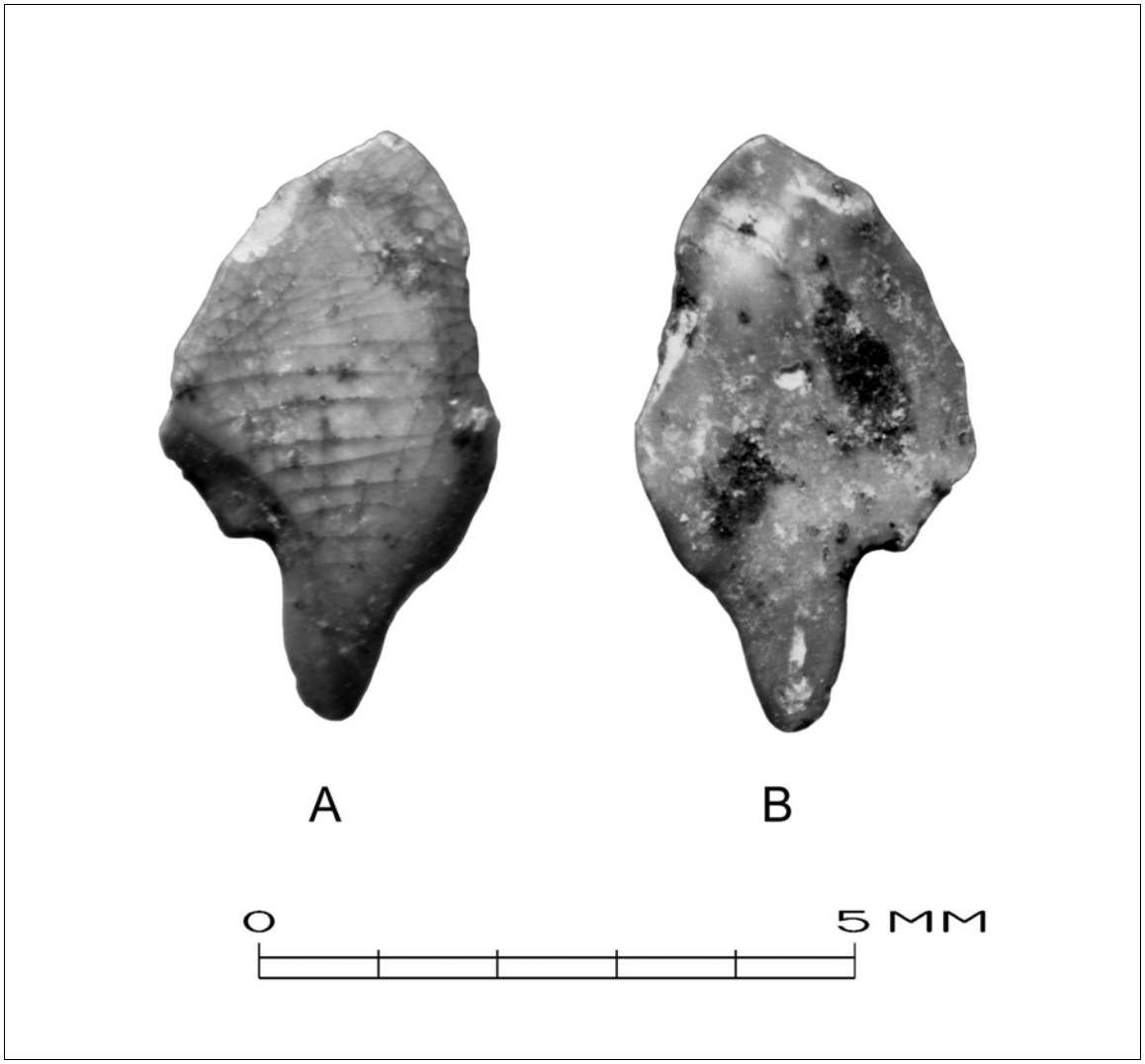

Figure 10.61. Gar Scale, Ambient Bone. Very small ganoid scale from unidentified gar (*Lepisosteus* sp.). A, exterior surface; B, interior surface of same specimen. N109 E96 (93.08-93.00 m), bulk matrix, coarse fraction.

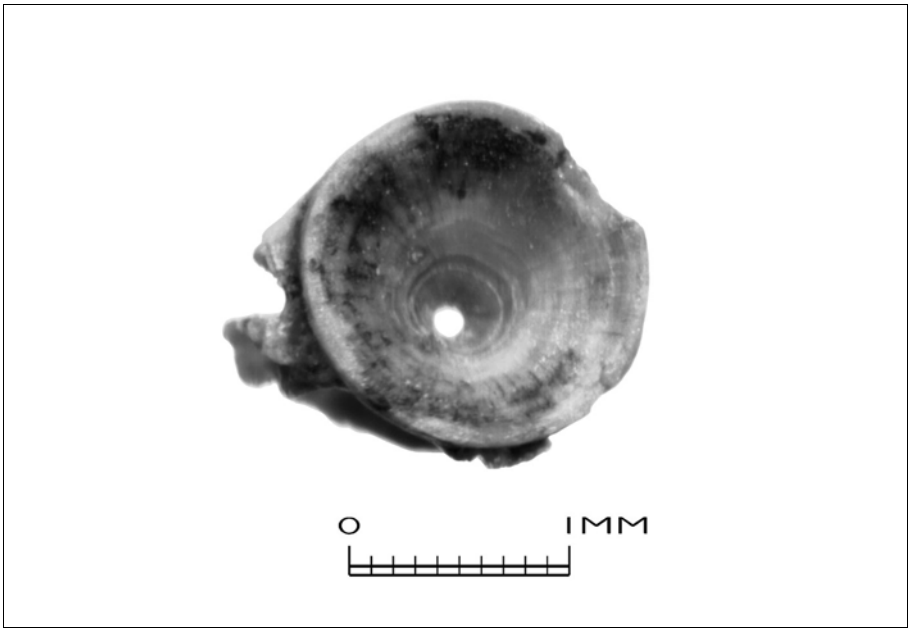

Figure 10.62. Ambient Bone, Small Fish Vertebra. Unidentified small, manganese-stained fish vertebra from coarse fraction of bulk matrix, N109 E96 (92.35-92.30 m). No lot number assigned yet.

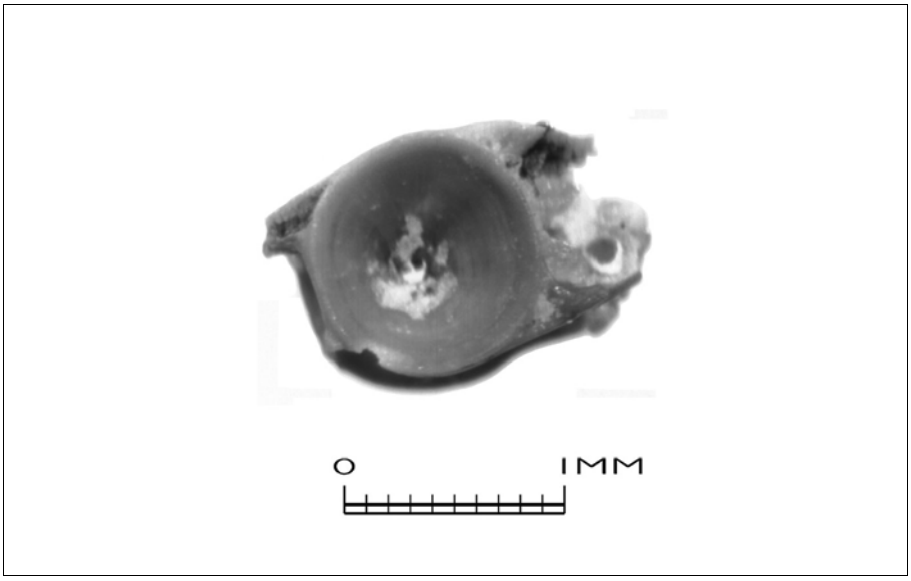

Figure 10.63. Ambient Bone, Small Fish Vertebra. Unidentified small fish vertebra from coarse fraction of bulk matrix, N109 E96 (92.35-92.30 m). No lot number assigned yet.

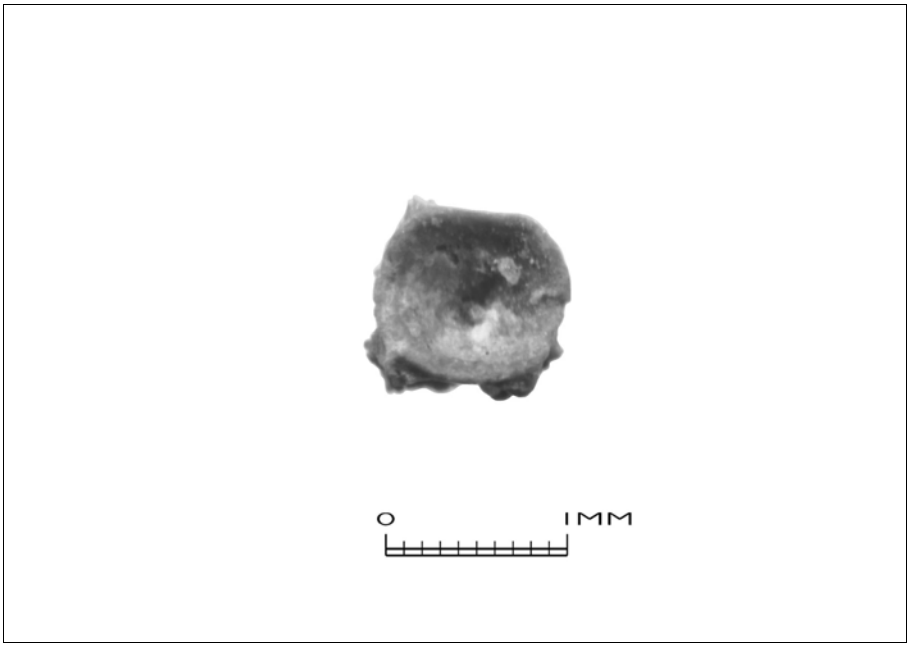

Figure 10.64. Very Small Unidentified Fish Vertebra From the Ambient Bone Assemblage. Centrum of very small vertebra recovered from coarse fraction of bulk matrix, N109 E96 (92.35-92.30 m). This specimen is poorly preserved and somewhat corroded in appearance, and may be from a poorly ossified juvenile.

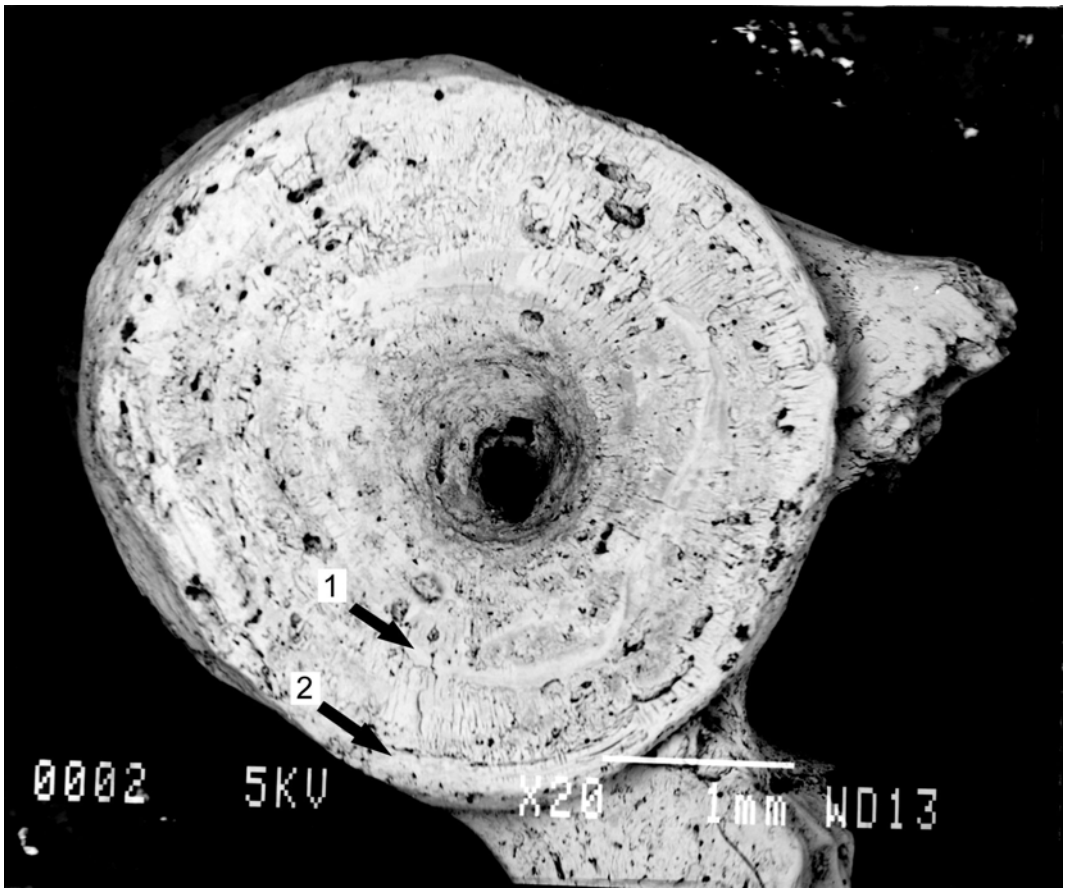

Figure 10.65. SEM Photo of Fish Vertebra. This vertebral centrum of a small unidentified fish comes from the hearth deposit and was acid-etched with 10% HCl before scanning electron microscopy; the corroded appearance is due to this etching, not to taphonomic decay. The contrast has also been heightened to emphasize bone texture. Arrows 1 and 2 mark the end of warm-season growth (porous radial bone structure) and the beginning of cold-season dormancy (dense lamellar bone growth). Death of this individual appears to have occurred at the end of the second winter (?). N113 E98 (92.50-92.40 m), lot B-105. Bar scale is 1 mm long.

None of these specimens has been identified beyond the Class level, but all are assumed to be freshwater teleosts. Most are from small fish, minnow-sized to panfish sized, although six spine fragments, a tooth, and a couple of vertebrae come from somewhat larger fish; some of these larger specimens come from the hearth deposit, although most of the fragments there are from small fish. The ambient fauna specimens must have come from Coleto Creek or from a small spring run, if there was one nearby. On the other hand, if the hearth deposit specimens, as I believe, came from a latrine area, they could have originated in any stream within human foraging radius, including the Guadalupe River. The smaller fish could perhaps represent any number of different families, such as the Cyprinidae (minnows), Poeciliidae (livebearers), Centrarchidae (sunfish), Percidae (perch), and others. Coleto Creek has representatives of all these (Table 10.4). The red shiner (*Cyprinella lutrensis*), western mosquitofish (*Gambusia affinis,*) and centrarchids (usually juveniles) like the bluegill (*Lepomis macrochirus*) were the most common fish collected in the pre-inundation survey (Murray, Jinnette and Moseley 1976:12-13). A number of the vertebrae compare well in size with typical centrarchids (Fig. 10.65), but there are also many from very small fish (Figs. 10.62-10.64) or juveniles.

Vertebral centra were the most abundant elements recovered. As is usually the case with archeological material, the neural and hemal spines, and often the basapophyses are broken off. Of the specimens recovered, five could be classified as possibly cervical vertebrae, one as possibly a thoracic vertebra, three as either cervical or thoracic, three as caudal, and 16 as unclassifiable. All of the caudal vertebrae occurred in the hearth deposit, where tail vertebrae might not be expected as dietary remains, but they were fairly small. The 24 specimens from the hearth deposit that could be measured had a

mean centrum diameter of 3.19 ± 0.69 mm (range, 1.8-4.3 mm). The single vertebra from the ambient fauna measured 3.8 mm in diameter. Seventeen of the 24 measurable vertebrae were slightly oblong rather than perfectly circular in sectional view, with the minimum diameter averaging about 92% of the maximum. The longer axis is dorso-ventral in some specimens, lateral in others.

Growth rings were also examined in these vertebrae, using surface inspection and conventional light microscopy. As an experiment, one specimen (Fig. 10.65) was etched in dilute HCl acid and then photographed with a scanning electron microscope to see if growth ring definition could be enhanced. Growth ring studies were done as part of a paleontology class project (Brown 1990). Table 10.25 shows the results of ring counts. Many of the ring counts are somewhat tentative as a result of poor ring definition or degradation of the centrum surface or edge. Few could be counted with absolute confidence. The "tentative" counts represent the best guess, and if these are added to the definite counts, there appear to be six specimens each of three, four, and five-year old fish (one of these may possibly have six rings), one that is either one or two years old, and five specimens where no count at all is possible. Among other things, these counts help greatly to define the minimum number of fish present in the hearth deposit. Based on ages, there must be at least three or four individuals present, all of different ages.

If the outer edge of the centrum is not too corroded, it is often possible to determine the season of death for the individual. In the simplest case, vertebral facets typically show wide, light-colored bands of porous bone alternating with narrow, dark-colored bands of dense bone. The porous bone is a result of rapid bone growth during the warm season, when the metabolic level of the fish is highest and assimilation of calcium

through the gills and phosphorous from the diet is at a peak (fish are ectotherms and their activity level depends on water temperature). The hypermineralized dense bone is laid down in the cold season, when metabolic levels are minimal and bone growth is slow. It is important to note that "cold season" and "warm season" correspond to water temperature, which is considerably lagged behind air temperature during the course of the year. In Texas, dense bone growth may occur as late as late April (Brown 1990:6).

Table 10.25. Ring Counts of Fish Vertebrae From the Hearth Deposit.

Specimens with 1-2 rings	1
Specimens with 3 rings	
definite	2
tentative	4
total:	6
Specimens with 4 rings	
definite	2
tentative	4
total:	6
Specimens with 5 rings	
definite	1
tentative	5
total:	6
No count possible	5
Grand total	24

The terminal growth rings were examined and classified for 26 vertebrae from the hearth deposit. Both vertebral facets were inspected, classified separately, and checked for consistent classification. In several cases, growth rings were too poorly defined, the terminal edge was corroded, or the facet was too carbonate-encrusted to allow determination. Of the 26 specimens categorized, none had obvious evidence of porous bone forming the terminal ring. Nine had terminal rings composed of dense bone, six were classified as "probably dense," and four were classified as "uncertain, possibly dense." Seven specimens were too obscure or damaged for classification. In summary, the evidence suggests that probably all of the fish in the hearth deposit were killed and eaten during the cold season. In contemporary climatic conditions, this might represent October/November through April, but the span might have been somewhat different at the end of the Pleistocene. The consistency of the seasonal classifications is further support for the notion that the hearth deposit represents a relatively short-term event.

Birds, unidentified, small (Figs. 10.31, F; 10.43, D-F; 10.46, G; 10.51, F-H)

Element	Ambient bone NISP	Hearth deposit NISP
lower beak		1
coracoid	1	
ulna		2
radius		1
femur	1	
distal phalanx		1
humerus	1	
carpometacarpus		3
long bone shaft fragments	2	10

All of the bird material comes from relatively small birds, none identified. A beak (Fig. 10.46, G) comes from a small passerine bird. The remaining material is described as "small," sparrow-sized, bluejay-sized, or quail or pigeon-sized. The kind of habitat represented is unknown.

cf. *Sceloporus* sp. (? possible spiny lizard)
Hearth deposit (N113 E98, 92.443-92.400 m, lot B-106)
1 vertebra

Bill McClure identified this item as "a vertebra of a small lizard, perhaps subadult *Sceloporus*." The identification is therefore quite tentative, based mainly on the size, and should not be considered definitive – the vertebra might have come from some other kind of iguanid lizard. There are three species in this genus in the region: *Sceloporus olivaceus*, *S. undulatus*, and *S. variabilis* (Dixon 1987:Maps 78, 80, 81). These are diurnal lizards, most likely found in brushy or rocky areas; *S. olivaceus* is arboreal, the other two terrestrial (Vermersch 1992).

Lizards, unidentified (Fig. 10.47, B, B'; 10.50, bottom row)
Ambient fauna
1 vertebra

Hearth deposit
6 vertebrae
4 unidentified fragments

All this material comes from small unidentified lizards. The dentary fragment in Fig. 10.47 comes from an unstudied lot of hearth deposit bone.

Snake or lizard, unidentified
Hearth deposit (N113 E98, 92.443-92.400 m, lot B-106)
3 vertebra fragments

These are fragmentary Squamata, but cannot be assigned to either snake or lizard.

Virginia striatula (Rough earth snake)
Ambient fauna: N110 E102, 92.45-92.40 m, lot B-46)
1 vertebra

This small vertebra retrieved from a matrix sample is the only specimen, although three other vertebrae are classed as Natricinae (see below). The rough earth snake is a small fossorial species (adults only about 18-25 cm long) reported from both the counties of Victoria and Goliad. According to Werler and Dixon,

> This abundant reptile inhabits the eastern half of the state, where it is likely to be encountered in almost any region with damp soil and debris for concealment. Suitable habitat includes pine woods, hardwood forest, sparsely wooded rocky hillsides, swamp edge, and grasslands (Werler and Dixon 2000:327).

This snake is chiefly nocturnal (although Vermersch and Kuntz 1986:102 say it is diurnal), and when on the surface can be found under rocks, logs, or leaf litter, often in wooded creek bottoms (Vermersch 1986:102). Leaf litter seems to be an important component of its habitat and most captures are in wooded areas (Clark 1964:288). This species is also more tolerant of cold weather than other snakes. It can be found aboveground under cover in the winter as long as temperatures are above 50° F. One was collected near Goliad on February 10, 1969 (Karges 1978:121). It may burrow into soft soil, occupy the burrows of other animals, or crawl into dead trees (Werler and Dixon 2000:327). It is a very small and slow-moving species, and apparently is limited by soil moisture (in Kansas, for example, it is found only in the southeastern corner of the state), but active after rainfall. Clark (1964:Fig. 13) found captures peaked in March. These snakes may occur in high population densities, 229-348 per hectare having been recorded in Brazos County. This is a good example of a reclusive species, and one that could be recovered by someone looking for occupied eastern mole burrows. It has been recovered

in the Clear Creek fauna (Holman 1963:161-162, as *Haldea striatula*), from Lubbock Lake (Johnson 1987:Table 7.1, as *Virginia* cf. *V. striatula*), and from 41 CH 161, at Cotton Lake in Chambers County (McClure 1997).

Natricinae (*Storeria dekayi texana* or *Virginia striatula*; Texas brown snake or Rough earth snake)
Hearth deposit (N113 E98, 92.443-92.400 m, lot B-106)
3 vertebrae

Three vertebrae are identified as from a colubrid snake of the subfamily Natricinae. These could either be from Texas brown snake or Rough earth snake. Both are similar small fossorial snakes, although the Texas brown snake is slightly larger (23-33 cm long). Like the Rough earth snake, it is a cold-tolerant, reclusive inhabitant of wooded creek bottoms and leaf litter; it may be common in marsh and mesic grassland (Frese 2001:14). Its geographic range extends farther westward (onto the Llano Estacado) than the Rough earth snake, so it is probably slightly more tolerant of arid conditions. The Texas brown snake feeds mainly on earthworms, slugs and snails and may be specially adapted for feeding on snails (Werler and Dixon 2000:266-267). According to Vermersch and Kuntz (1986:81) it is diurnal in spring and fall, nocturnal in hot weather.

> …it shows a preference for wet, shaded places that offer some ground cover and enough surface litter where hiding places, earthworms, and other prey abound. Such habitations include river and creek floodplains and their slopes, swamps, freshwater marshes, damp woods, and even water-filled ditches (Werler and Dixon 2000:265).

Storeria cf. *S. dekayi* occurs in the Easley Ranch (Holman 1995:151) and Tonk Creek faunas (Parmley and Pfau 1997), and *S. dekayi* at 41 FB 32 (McClure 1989). Even though these vertebrae cannot be separated into *Virginia* or *Storeria*, the two taxa are so similar in habits that the environmental significance is the same.

Colubrinae (unidentified snakes in the subfamily Colubrinae)
Hearth deposit (N113 E98, 92.443-92.400 m, lot B-106)
12 vertebrae

The Colubrinae are another subfamily of the Colubridae. Present are two vertebrae from an unidentified snake with an estimated snout-vent length of about 60 cm, plus ten smaller vertebrae, of which four are similar to *Diadophis punctatus* (ring-necked snake). Ring-necked snakes are not currently recorded from the region. The Prairie ring-necked snake (*Diadophis punctatus arnyi*) occurs on the Edwards Plateau and to the northwest; the Mississippi ring-necked snake (*Diadophis punctatus strictogenys*) occurs on the upper Texas coast (Werler and Dixon 2000:90, 96) and might be a better geographic match for the Berger Bluff specimens. Judging by its distribution, the Mississippi subspecies must have higher moisture requirements.

The ring-necked snake is another reclusive, nocturnal, fossorial snake that shelters under decaying logs, rotting tree stumps, leaf litter, or in the loose bark of trees. It normally hibernates from October to early April (Werler and Dixon 2000:97). The Prairie subspecies feeds on earthworms, slugs, insects, salamanders and their eggs, frogs, lizards, and other snakes; in a study in Virginia, 80% of the diet consisted of salamanders (Werler and Dixon 2000:93). This is of interest in view of the relatively large numbers of small-mouthed salamanders in the bench deposits. Since *Diadophis punctatus* is not currently reported from the region, the possibility should also be considered that the vertebrae actually belong to another of the small fossorial species in the area. Paleontological and archeological occurrences are rare. It is presumably the Trans-Pecos subspecies, *D. punctatus regalis*, that has been found at Fowlkes Cave (Parmley 1990:270-271). *D.*

punctatus has also been found at Cave Without a Name (near Boerne; Hill 1971) and 41 CH 161 (Chambers County; McClure 1997).

cf. *Rhinocheilus lecontei* (Long-nosed snake)
Hearth deposit (N113 E98, 92.443-92.400 m, lot B-106)
1 vertebra

The Texas long-nosed snake, *R. lecontei tessellatus*, occupies the western two-thirds of the state (Werler and Dixon 2000:247). Its eastern range limit closely parallels the 90 cm annual precipitation isohyet in north Texas and the 70 cm isohyet in south Texas, which brings it close to Berger Bluff. It is not reported for the counties of Goliad or Victoria, but apparently has been reported in the counties of De Witt and Karnes.

This somewhat reclusive snake clearly belongs to the minority of xeric upland species found in the Berger Bluff fauna, along with the pocket mice and kangaroo rats, which it occasionally eats. It is a medium to large snake, usually 51-76 cm long, preying mainly on lizards and occasional small snakes. It lives in dry habitats with sandy soil in grassland or chaparral (Werler and Dixon 2000:247) but may live in oak and hackberry stands in sandy areas (Vermersch and Kuntz 1986:73). Unlike the other fossorial species, this one is an active burrower, and likely derived from the sandy upland habitat rather than the Coleto Creek floodplain. It is also somewhat cold-tolerant, active in temperatures as low as 59° F. This species has been recovered from Pendejo Cave (Harris 2003:Table 4.3), Howell's Ridge Cave (Van Devender and Worthington 1977:94), the Slaton Local Fauna (Holman 1995:151), Fowlkes Cave (Parmley 1990), Cave Without a Name (Hill 1971), Baker Cave (Chadderdon 1983:Table 8) and Lubbock Lake (Johnson 1987:Table 7.1).

Nerodia sp. (unidentified water snake)
Ambient fauna (N109 E96, 92.80-92.75 m, lot B-129)
1 vertebra

A single large vertebra was recovered near the top of the unit in stratum $2D_2$. There are three different water snakes of the genus *Nerodia* in Coleto Creek Reservoir (Table 10.3). The Blotched water snake (*Nerodia erythrogaster transversa*), the Broad-banded water snake (*Nerodia fasciata confluens*) and the Diamond-backed water snake (*Nerodia rhombifer rhombifer*) all occur in the area (Werler and Dixon 2000:201-205, 217-219). In addition there are two species, *Nerodia clarki clarki* and *Nerodia cyclopion*, that usually occur in brackish water habitats along the coast. These are less likely candidates, but might be within the foraging radius of a predator. The following are composite comments intended to apply to the three chief species.

These are all large snakes (76-122 cm), especially the Diamond-backed water snake, which can reach a length of over 1.73 m. They are swimming snakes, the first two preying on frogs, toads, salamanders, and crawdads and/or fish. The Broad-banded water snake spends about 60% of its time in the water (Werler and Dixon 2000:204); these snakes prefer sluggish water with emergent vegetation, and this one probably lived in Coleto Creek, although it might also be found in a nearby spring run. When out of the water, these snakes may be found in grassy areas. They are also mostly nocturnal in hot weather, but may be diurnal in the winter, and according to Vermersch and Kuntz (1986:62), the Diamond-backed water snake is active year-round in south-central Texas. When on land in the summer, it takes refuge under logs or litter, or in crawdad burrows. These snakes are also arboreal, often hanging off tree limbs. They are also pugnacious and aggressive when approached by humans. Various species of *Nerodia* (not necessarily

the ones discussed here) have been found in paleontological localities such as the Gilliland, Slaton, Clear Creek, and Howard Ranch (Holman 1995:150-152) and Tonk Creek (Parmley and Pfau 1997) faunas, Fowlkes Cave (Parmley 1990:271), Cave Without a Name (Hill 1971), and occasionally in archeological sites such as Lubbock Lake (Johnson 1987:Table 7.1), Rex Rodgers (Hughes and Willey 1978:107), the Aubrey site (Yates and Lundelius 2001:Table 8.1, 8.3) Loyola Beach (Smith 1986:Table 9), and the Buckeye Knoll site (Weinstein 1992:Table 7-47, 7-48) and three sites at Allens Creek (McClure 1987). The genus was also reported (as *Natrix* sp., outmoded taxonomy) from the upper deposits at Berger Bluff by Flynn (1983).

Viperidae (= Crotalidae; unidentified vipers and pit vipers)
Hearth deposit (N113 E98, 92.50-92.40 m, lot B-105)
2 vertebrae (1 of which is caudal)

Two vertebrae from unidentified poisonous snakes were found in the hearth deposit. There are probably at least five kinds of vipers and pit vipers in the region (Table 10.3, 10.6): western cottonmouth (*Agkistrodon piscivorus leucostoma*) two subspecies of copperheads (*Agkistrodon*), and two rattlesnakes (*Crotalus*). In addition to the familiar western diamondback, a small population of canebrake rattlesnakes lives on lower Coleto Creek. The cottonmouth is, of course, likely to be found along Coleto Creek. Copperheads and the coral snake would be found in deciduous woodland, either in the creek bottom or possibly in more open postoak woodland on the sandy uplands. Rattlesnakes could be found in any brushy area, especially on the valley slopes or at the edge of gallery forest overlooking patches of prairie.

Rattlesnakes are fairly well documented as human food items in the borderlands and Great Basin (Brown 1988:9; Driver and Driver 1963:61; Pennington 1969:144; Smith 1974:51) and indeed, are still eaten in Texas today. Among the Cora,

> The iguana and the rattlesnake are both eaten. Of the snake, only the middle part of the body is used owing to the Cora belief that venom contained in the head and tail makes these parts unpalatable. This kind of practice and belief is also found among the Seri (Malkin 1958:75).

A captivity account describing the Comanche (?) says

> …if they could find a big rattlesnake they would kill him before he was disturbed so as to prevent him from biting himself. Then they would cut off his head about twelve inches back and cut off the tail, taking the middle part and boil it until the flesh would drop off the bones (Smith and Smith 1977:122).

Viper and pit viper vertebrae are fairly common occurrences at archeological sites of all ages in most parts of the state (Alexander 1963:Table 1; Lord 1984; Fox 1979:Table 16; Yates and Lundelius 2001:Table 8.1, 8.3; Johnson 1987:Table 7.1; Weinstein 1992:Table 7-19, 7-24, 7-29, 7-30, 7-35, 7-47, 7-48; Wright 1997:241; Steele *et al*. 1999:Table 24; Nash *et al*. 2002:25). Sometimes heat-altered examples are found (Thornton and Smith 1995:300-301).

Snakes, unidentified (Figs. 10.29, C; 10.31, D; 10.50)
Ambient fauna
2 vertebrae, both small

Hearth deposit
5 caudal vertebrae
4 small vertebra fragments

These vertebrae cannot be identified beyond the suborder Sepentes.

Emydidae (?*Pseudemys concinna* or *Trachemys scripta elegans*, River cooter or Red-eared slider; Figs. 4.54, 10.17, 10.66, 10.67)
Ambient fauna (Cutbank, stratum 1, 92.12 m and 92.08 m)
1 hypoplastron fragment
1 epiplastron fragment
6 additional associated plastron fragments

All of the turtle material is from the ambient bone assemblage, none from the hearth deposit. These plastron fragments come from a single unidentified Emydid turtle. The Emydidae include map, cooter, slider, and box turtles. McClure identified these as either *Pseudemys concinna* or *Trachemys scripta*, but the cooter that is reported for the area is actually *Pseudemys texana*, the Texas river cooter (Dixon 1987:Map 55) and perhaps that is a more likely candidate.

In any case this is an aquatic turtle, evidently a slider or cooter. These are medium-sized turtles, about 15-28 cm long with hingeless plastrons (Ernst 1989:Fig. 4.4), found in ponds and lentic streams, usually with soft mud bottoms and abundant aquatic vegetation. This is exactly the kind of hydrologic system reconstructed for Coleto Creek in Chapter 4. The familiar red-eared slider (subspecies *elegans*) occurs over most of the state except for parts of far west Texas and extends into the Mississippi Valley and upper Midwest (Ernst 1989:Fig. 4.6). Tucker, Filoramo and Janzen (1999:199) measured carapace lengths for females at 21.35 ± 0.14 cm in Illinois, and discovered that the heads and legs of dead turtles were removed by predators. The Texas river cooter is endemic to the Colorado, Brazos, and Guadalupe river systems (Vermersch 1992:109). These turtles may be seen collectively basking on logs or brush in creeks and may also move individually overland between bodies of water.

The specimens consist of one large hypoplastron fragment (7.8 x 3.2 cm, maximum thickness 5.94 mm); one smaller fragment, apparently of anterior margin of epiplastron (4.0 x 3.3 cm; maximum thickness 6.14 mm), plus six small tabular fragments, one of which has two parallel cut marks on the interior (?) surface. All were found closely associated and apparently are fragments of the same plastron. The cutmarks appear to be evidence of human modification, but there is no indication of heat alteration.

Turtles were usually processed by roasting them in the shell in an open fire. The following account of the Comanche (?) in the early 1870s probably applies to tortoises (likely *Gopherus berlandieri*) rather than aquatic turtles, but the method is the same:

> The Indians are very fond of dry land terrapins, or turtles, and when they found these testudos crawling about they lost no time in roasting them. One day Tosacowadi went out and brought in a great number of terrapins, as many as he could carry in a sack on his horse. While he was gone the squaws and I dug and gathered a lot of wild potatoes, a bushel or more. When the terrapins were brought into camp we built a big fire and threw the terrapins in alive, and we had great sport cooking them. They would get pretty lively in trying to get out of that fire. Being naturally a slow creature, it was really surprising to see how fast they could move when they get hot. We kept them engaged until they were all dead and cooked, and then we raked them out of the fire, cracked them open with our tomahawks, and with the roasted potatoes we had a feast (Smith and Smith 1977:90-91).

This method should result in heat alteration on both carapace and plastron, a condition frequently seen in archeological specimens (Rhodin 1992). An alternative method used by the Seminole was to remove the plastron first. In that case, only the carapace should show heat alteration:

> Most meats are boiled, but turtles are not infrequently roasted before the fire. The Indians seldom take the trouble to kill the unfortunate reptiles before commencing

to prepare them for food -–they merely cut off the plastron and butcher the animal alive and kicking, when it is set up before the fire and roasted in its own oven (Skinner 1913:76-77).

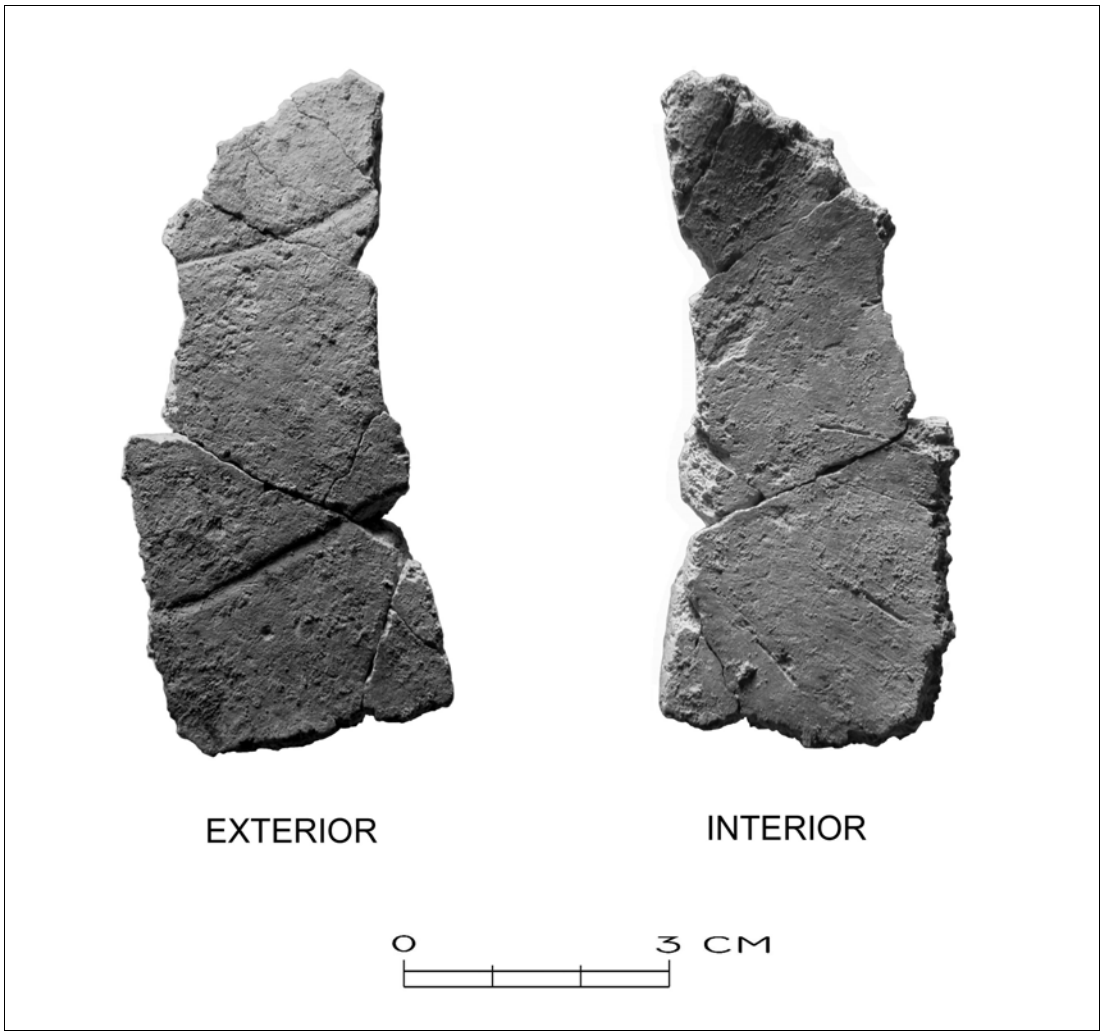

Figure 10.66. Turtle Plastron Fragment From the Cutbank. Both sides of fragment of left hypoplastron (unidentified Emydidae, perhaps *Trachemys scripta* or *Pseudemys concinna*). Grooves (sulci) on exterior are natural surface sculpturing. See Fig. 4.54 for photo, Figs. 3.1 and 4.22 for location. This specimen is unmodified, but an associated smaller fragment (Fig. 10.17) has cutmarks. Stratum 1, lot B-154 (ca. 92.08-92.13 m).

This would result in the kind of evidence seen on the stratum 1 specimen – cutmarks, but no heat alteration.

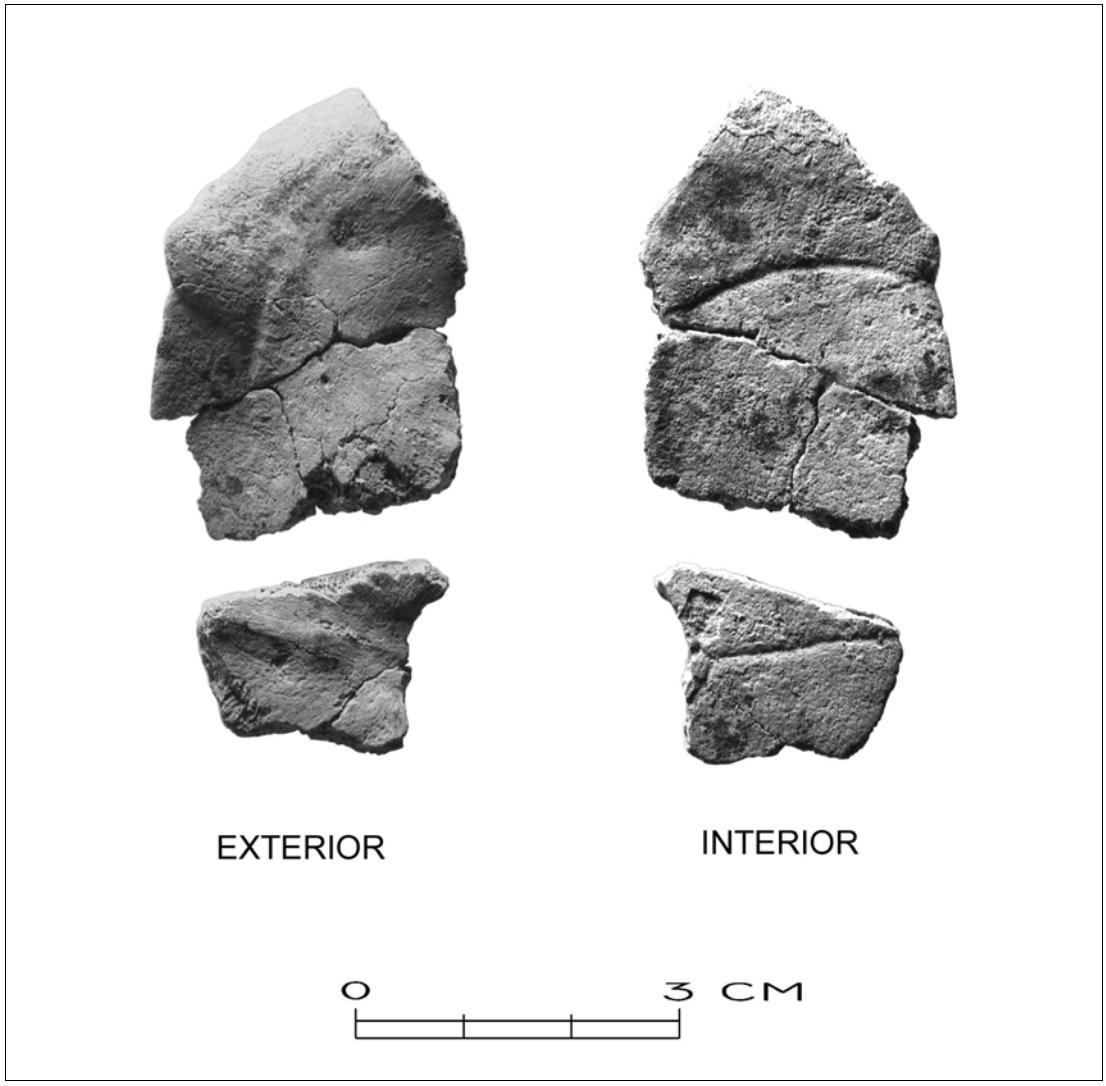

Figure 10.67. Another Turtle Plastron Fragment From the Cutbank. Views of both sides of plastron fragments (unidentified Emydidae, perhaps *Trachemys scripta* or *Pseudemys concinna*). The larger fragment above is the left epiplastron. See Figs. 3.1 and 4.22 for location. These fragments do not show clearly in Fig. 4.54, but were found nearby. They are also unmodified, but an associated smaller fragment has cutmarks. Stratum 1, lot B-154 (ca. 92.12-92.15 m).

Kinosternidae (unidentified mud or musk turtles; Figs. 10.68, 10.69)
Ambient fauna (N109 E96)
1 right pleural plate (two joining fragments), 92.55-92.50 m, lot B-134
1 peripheral plate fragment, 92.35-92.30 m, lot B-139

McClure identified a pleural plate as probably *Sternotherus odoratus* (stinkpot turtle), but possibly a subadult mud turtle (*Kinosternon* sp.). The pleural plate is 14.1 mm long, 9.15 mm wide, 0.9-1.7 mm thick; it is arched, from near the medial ridge, and has small conical pits as part of the surface sculpturing (Fig. 10.68). Pits like these also occur on box turtle carapaces (Carpenter 1956) and are a natural feature of the shell. The peripheral plate fragment is identified only as Kinosternidae, mud or musk turtle. It is 9.5 mm long, 5.9 mm wide, 1.1-1.95 mm thick, and has a cavity for rib insertion on one edge (Fig. 10.69).

Musk turtles are rather small aquatic turtles, about 8-10 cm long (up to 13.7 cm), found throughout east and central Texas. It is a bottom-dwelling turtle found in lentic creeks, sloughs, swamps, and ponds with mud bottoms, and it tends to stay in the water, not often emerging onto land. Basking is done partially submerged. As its name indicates, it has musk glands designed to repel predators.

Turtles, unidentified
Ambient fauna
4 carapace fragments (2 possible Kinosternidae, 1 possible Emydidae)

There are two carapace fragments that do not join but were probably one broken in excavation (Fig. 10.70). From a small turtle, these may be Kinosternidae, but are uncertain. Both are slightly heat-discolored (N109 E96, 92.25-92.20 m, lot B-143, stratum 2A) and are from the fill of Feature 7. Another carapace fragment is from a

medium-sized turtle, perhaps Emydidae (N109 E96, SW half, 92.15-92.10 m, lot B-146, stratum 2A). The remaining carapace fragment is too small for any kind of identification.

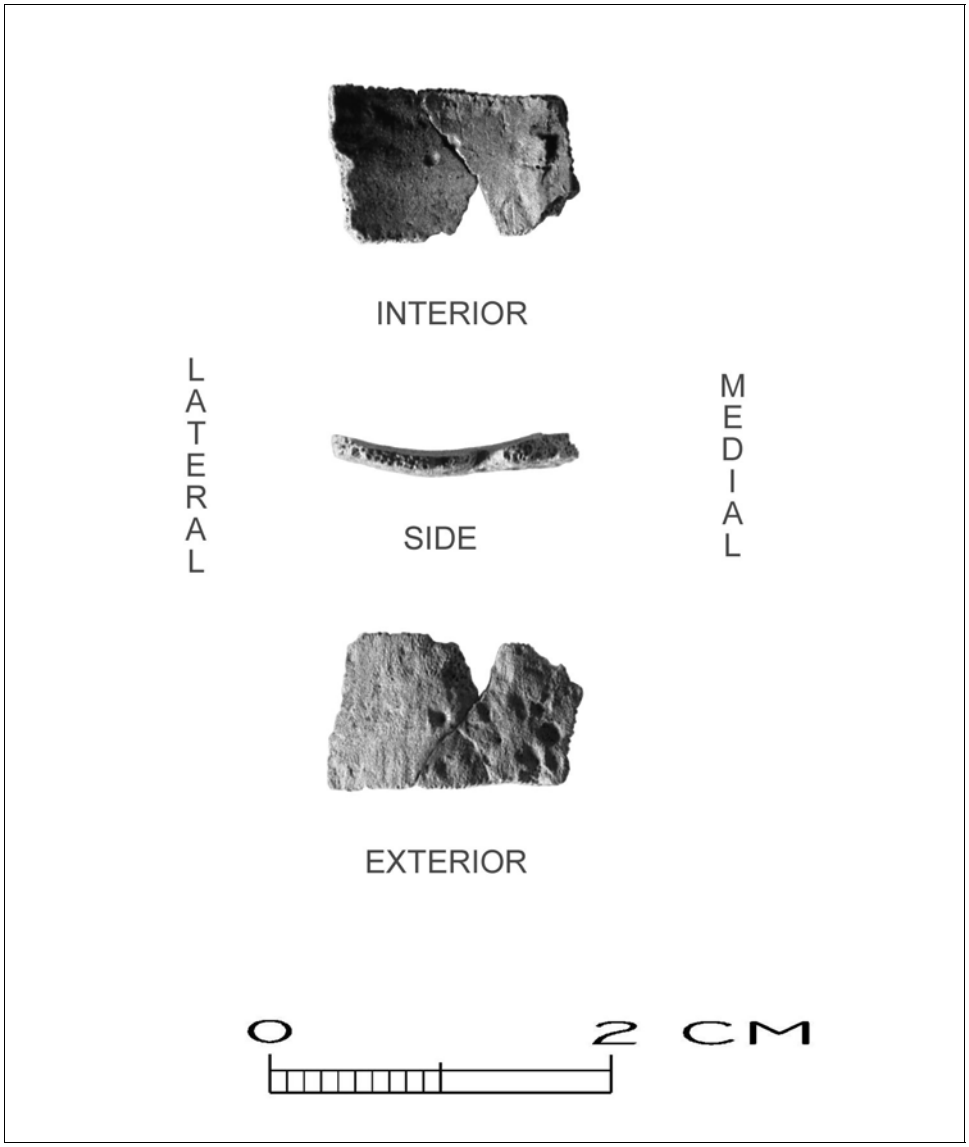

Figure 10.68. Turtle Carapace Fragment, Ambient Bone. Right pleural plate from carapace of a musk or mud turtle (Kinosternidae, probably *Sternotherus odoratus* but possibly subadult *Kinosternon* sp.). Interior, side, and exterior views of the same specimen are shown. Conical pits on the exterior are part of natural sculpturing. N109 E96 (92.55-92.50 m), lot B-134.

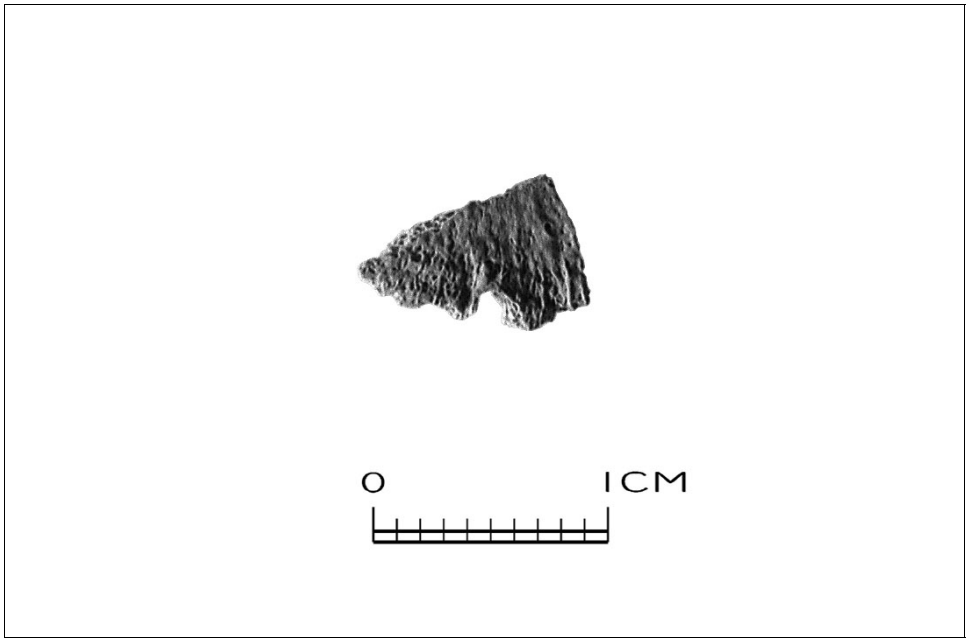

Figure 10.69. Turtle Carapace Fragment, Ambient Bone. Small fragment of peripheral plate from carapace of a mud turtle (Kinosternidae sp.). Edge indentation is a rib insertion point. N109 E96 (92.35-92.30 m), bag 2 of 2, lot B-139.

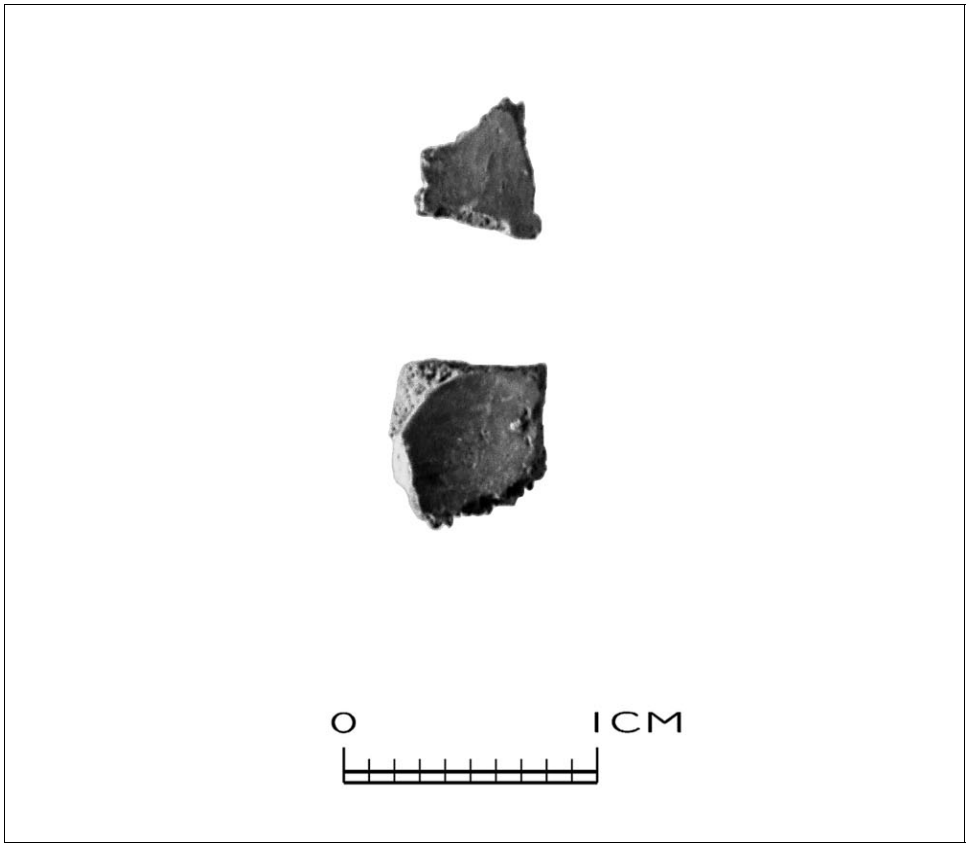

Figure 10.70. Turtle Carapace Fragments, Ambient Bone. Two fragments of unidentified carapace from a small turtle (perhaps Kinosternidae) do not join but are evidently pieces of one broken in excavation. Both appear slightly heat-discolored, probably from vertebral plate of carapace. These were found in the fill of a small pit, Feature 7. The larger fragment has part of a suture along one edge. Interior surfaces are shown here. N109 E96 (92.25-92.20 m), Feature 7 fill, lot B-143.

Bufo sp. cf. *?B. americanus?* or *?B. houstonensis* (American or Houston toad)
Hearth deposit (N113 E98, 92.443-92.400 m, lot B-106)
1 left ilium fragment

This specimen is in the genus *Bufo*, but species assignment is very problematical. McClure assigned it to either *B. americanus* or *B. houstonensis,* but *Bufo americanus* as currently recognized is confined to extreme northeastern Texas, and *B. houstonensis* to an area northeast of Goliad County no closer than Columbus (Dixon 1987:Maps 8, 28). There are three other toads present in the region that perhaps should also be considered better candidates: Texas toad (*B. speciosus*), Gulf Coast toad (*B. valliceps*), and Woodhouse's toad (*B. woodhousei*). Mulcahy and Mendelson (2000) have proposed revising Texas and Louisiana *B. valliceps* to *Bufo nebulifer*.

The Gulf Coast toad is the only toad species recorded during the pre-inundation ecological survey (Table 10.3) and is the one most commonly seen in the area. American and Houston toads are small toads, about 5-11 cm long, while the Gulf Coast and Woodhouse's toad are slightly larger, about 5-13 cm long. Most toads are closely tied to water and are chiefly active at night, especially after rainfall. Like other amphibians, they are sensitive to humidity. Blair (1960:173) suggests populations may be limited by access to damp ground for burrowing. Most lay their eggs in ponds or other still water sources. The Texas toad is the most arid adapted, and burrows in loose, sandy soil. Toads also have parotoid glands that secrete toxins to ward off predators, and in some cases these are fatal to the predator. Nevertheless, toads are often preyed upon by snakes and raptors. This might be taken as a strong argument that these remains do not represent human food items, but it is useful to remember that ethnographies show hunter-gatherers who predate malodorous or venomous animals (such as skunks or rattlesnakes) always know how to

remove the threatening glands when processing the animal. The small sample of toad remains known from the bench deposits consists of forelimb elements and part of a pelvis.

cf. *Bufo* sp.
Ambient fauna
2 proximal ends of humeri

Hearth deposit
1 proximal left radius-ulna

These long bone fragments resemble toad rather than frog, but cannot be identified further. Toads seem rarely to be reported in the archeological literature, although *Bufo* sp. has been reported from 41 CL 70 and 41 CL 59 (Weinstein 1992:Table 7-24, 7-35), the Asa Warner site (Wright 1997:241) and a few others.

Rana catesbeiana (Bullfrog; Fig. 10.29, G)
Ambient fauna (N109 E96, 92.50-92.45 m, lot B-135)
1 urostyle fragment (articular end)

A single urostyle fragment from a bullfrog was found near the upper contact of stratum 2C, at about the same level as the possible surface of origin of Feature 7. Whether it is associated in some way with this small pit is unknown. The maxillary fragment shown in Fig. 10.47, A, A' appears to be from a very large frog and is from an unstudied lot of material. It does not match comparative specimens of *Rana catesbeiana* closely, but is a better match for that than for other frog species. The bullfrog is native to south Texas (Neck 1981) and covers most of the state except some parts of the Trans-Pecos (Dixon 1987:Map 36). It is the largest true frog in North America, up to 20 cm long (legs extended; average about 9-15 cm) and 0.5 kg in weight. It is an aquatic frog, usually living in ponds, marshes, stream backwaters, or other lentic habitats, seldom

straying far from water. It prefers warm weather and hibernates during the winter, and is mostly nocturnal. These frogs are opportunistic generalists in diet, eating snails, snakes, worms, insects, crawdads, frogs, small fish, mammals, and birds. Predators of bullfrogs include cottonmouths, otters, water snakes, Mississippi kites, broad-winged hawks, and people. Although there are many reports of *Rana* sp. in Texas archeological sites, fewer than might be expected have been identified as *Rana catesbeiana*. Examples have been found at the Wilson-Leonard (Balinsky 1998:Table 35-2), Lubbock Lake (Johnson 1987:Table 7.1), 41 ZV 10 (Hester 1978:46) and 41 CH 161 (McClure 1997). Considering the large size of this frog, it is surprising that so few occurrences are reported in the archeological literature.

Rana cf. *R. berlandieri* (cf. Rio Grande leopard frog; Fig. 10.31, B, G)

Element	Ambient bone NISP	Hearth deposit NISP
urostyle	1	
humerus		1
pelvic girdle	1	
tibiofibula	1	1
ilium	1	3
phalanges	2	
metatarsal shaft fragment?		1

Most of the identified frog material is leopard frog. There are two right ilia and one left in the hearth deposit. One of the rights comes from an individual with an estimated snout-vent length of 6-7 cm, the other a length of 7-8 cm. The smaller of the two, plus a 9 mm long section of tibiofibula, come from Unit 2, where Feature 5 is located.

Curiously, the pre-inundation ecological survey (Espey, Huston & Associates 1976:Table 3-6) recorded only Southern leopard frog (*Rana sphenocephala*), not Rio

Grande leopard frog. The two have complementary but not quite parapatric distributions. The Rio Grande leopard frog is more arid-adapted, occupying south and west Texas. The Southern leopard frog, which seems to be the contemporary species, is more mesic-adapted and occupies the eastern part of the state (Dixon 1987:Maps 34, 38). The two species occur in separate leopard frog clades and are not very closely related (Zaldívar-Riverón, León-Regagnon and Nieto-Montes de Oca 2004:Fig. 4). Assuming the archeological material is correctly speciated, this seems to be one of few cases in the bench deposits where a more xeric species has been replaced in the modern fauna by a more mesic-adapted one.

Rio Grande leopard frogs are chiefly riparian stream-dwellers in creeks, rivers, and ponds. It is primarily nocturnal, and may burrow under rocks in the daytime (Garrett and Barker 1987:42). Like bullfrogs, they are also opportunistic generalists (Parker and Goldstein 2004).

Salamanders (Smallmouth salamander and unidentified salamanders; Figs. 10.29, A, B; 10.30, C; 10.35; 10.45, Q; 10.46, H, J; 10.48, 10.49)

Ambystoma texanum
Ambystoma cf. *A. texanum*
Ambystoma sp.
Salamander, unidentified
Salamander, possible

Element	Ambient bone NISP	Hearth deposit NISP
humerus		8
femur		5
unident. long bone fragment		29?
ilium		2
axis vertebra		1?
precaudal vertebra		21
caudal vertebra		1

unidentified vertebra	8	85

Figure 10.71. Smallmouth Salamander. Photo of *Ambystoma texanum* by John White; used with permission.

Two kinds of mole (= ambystomatid) salamanders are found in this part of Texas: the Smallmouth salamander (*Ambystoma texanum*, Fig. 10.71) and the Eastern tiger salamander (*Ambystoma tigrinum tigrinum*), both sympatric over a large area of eastern Texas (Dixon 1987:Maps 3, 4) and differing greatly in size. The Smallmouth salamander is a small one, about 11-18 cm long. Live body weight ranges from 8 g for males to 11 g for gravid females (Finkler and Cullum 2002:Table 1). The Eastern tiger salamander is much bigger, about 18-33 cm long. Apparently no salamanders at all were found in the pre-inundation survey (Table 10.3) of Coleto Creek Reservoir. Smallmouth salamanders are recorded from Victoria County, but I know of no records from Goliad County.

Although, as the list above indicates, there are different levels of uncertainty about the classification of the salamander material, I believe that all of it is probably *Ambystoma texanum*. The species is also know to hybridize with other Ambystoma species (Downs 1989:150). One vertebra in lot B-105 and three in lot B-106 were larger than usual, but not so large as to indicate *A. tigrinum*. Of the 18 vertebrae identified as *A. texanum* in lot B-106, 14 could be measured, and these have a mean length of 2.65 mm, range 2.4-3.4 mm; all of the centra are closed. One vertebra from lot B-106 has an open centrum. Most of the salamander material was found in the hearth deposit, where there are probably at least three individuals, but possibly more. An ilium and some vertebrae show evidence of heat alternation, suggesting these individuals were cooked. There is no cranial material at all in this collection – all of it is postcranial. Like others of its kind, Smallmouth salamanders are mostly body and tail. The tail is usually 40% or more of the total length, with males having longer tails (Bishop 1962:155). The head is small and the limbs are little more than vestigial. Vertebrae are the mostly commonly recovered and identified elements.

Mole salamanders are reclusive and nocturnal, preying on earthworms, beetles, spiders, and the like. They spend most of their time in burrows or under logs (Minton 1972:50), leaf litter and rocks, emerging at night, especially after heavy rains. Like other amphibians, they have low rates of metabolism and remain inactive in borrows when not actively foraging at night (Pfingsten and Downs 1989:6). They may occupy eastern mole burrows and have often been recorded in crawdad burrows in wetter habitats (Fiorentino 2002:3, 16). They have been recorded often being plowed up out of animal burrows. They live in mesic deciduous forests (Wicknick, Anthony and Reblin 2005). They may

also be common in marshland and mesic grassland (Frese 2001). In other parts of the country where there are ponds in upland settings, they may be found in drier upland forest, but the Coleto Creek catchment had no upland ponds until artificial stock ponds were built starting in the 1950s. Speaking of salamanders in general, Bishop (1962:12-13) says,

> Many species may be found by turning logs, piece of bark, stones, and rock fragments. Well rotted logs should be pulled apart and loose bark stripped from the trunks of standing and prostrate trees… Many terrestrial species, which have an aquatic larval stage in their life history, congregate in large numbers in or near the breeding waters and advantage should be taken of such assemblages. In this category are many of the species of *Ambystoma*.

These salamanders migrate en masse overland at night (often after or during rainstorms) to shallow breeding ponds where eggs are deposited, after which the males may disperse to moist refuges embedded in drier habitats at some distance from the ponds (McWilliams and Bachmann 1988:68; Smith 1934:399). In the summer months, adults can be found in creek beds, floodplain swamps, prairie, and rocky hillsides (Smith 1961:36). Harper and Guynn (1999) studied some other species of salamanders in North Carolina forests and discovered that densities were highest in moist sites, usually with northern or eastern exposures, and in areas with high densities of snails. They suggest that since salamanders eat snails, the snails serve as a necessary calcium source. If these findings apply also to *Ambystoma texanum*, it raises the interesting possibility that Smallmouth salamanders might have been attracted directly to Berger Bluff because of its moist habitat and abundant phreatic carbonate. Berger Bluff is essentially a carbonate island in a sea of Miocene and Quaternary quartz sand.

The presence of Smallmouthed salamanders in the bench deposits indicates not only the presence of wet habitat, but more specifically lentic bodies of water, because these salamanders must lay their eggs in still bodies of water. There must have been either closed depressions or at least partially obstructed sloughs or overflow channels in the Coleto Creek floodplain to provide suitable habitat. Abundant submerged vegetation is also important to serve larval salamanders as a refuge from predation. There are stream-breeding populations of *A. texanum*, but they are confined to headwaters beyond the reach of predatory fish (Downs 1989:144). The hydrologic regime suggested here is very consistent with the picture presented by the sediments, aquatic snails, freshwater mussels, and diatoms.

The ethnographic record for salamanders of any kind is almost nonexistent. Mexican salamanders (*Ambystoma mexicanum*) are still sold for human consumption in markets in Mexico. The Pomo denied eating salamanders, but used them in sweat baths (Barrett 1952). There are a few scattered references in the archeological literature. *Ambystoma* (?) vertebrae were found in human coprolites from Salts Cave, Kentucky (Watson 1969:55). The related species *Ambystoma tigrinum* has been recovered at 41 CO 141 (Yates 1987:Table 4.1), L. E. Robertson Shelter, Opilionid Shelter (Butler 1980:Table 12.13, 12.16), Lubbock Lake (Johnson 1987:Table 7.1) and at Pendejo Cave (Harris 2003:Table 4.2). Unidentified salamanders have been found at the Aubrey site (Yates and Lundelius 2001:Table 8.1, 8.3), the Wilson-Leonard site (Balinsky 1998:Table 35-1), the Panther Springs Creek site (Hulbert 1985:Table 31) Timmeron Rockshelter (Harris 1985:Table 4) and at 41 CH 36 (Dillehay and Davidson 1975:Table 9). Plethodontid salamanders are reported from 41 AU 38 (Lord 1981:Table IV-I). *A. texanum* also appears occasionally in the paleontological record (Holman 1965;

1995:152; Parmley and Pfau 1997). Aside from humans, predators of salamanders include raccoons, otters, possums, coyotes, snapping turtles, burrowing owls, barred owls, and screech owls.

Cryptotis parva (Least shrew; Fig. 10.30, D)
Ambient fauna (N109 E103, 93.14-92.90 m, lot B-2)
1 mandible

Hearth deposit (N113 E98, 92.443-92.400 m, lot B-106)
1 molar, M_1

Soricidae (Shrews, likely *Cryptotis parva?*; Fig. 10.43, C)
Hearth deposit (N113 E98, 92.443-92.400 m, lot B-106)
1 edentulous mandible

An edentulous shrew mandible was found in the hearth deposit, along with a loose tooth of *Cryptotis parva* which very likely goes with the mandible. The body of this very small insectivore averages about 6 cm long, and the weight is only about 4.5 g (range, 4.0-7.5 g). This species lacks the venom of shrews of the genus *Blarina*.

There are four kinds of shrews in the area: Southern short-tailed (*Blarina carolinensis*), Elliot's short-tailed (*B. hylophaga*), Desert (*Notiosorex crawfordi*), and Least shrew. The first two are eastern species, the third a xeric species occupying the western part of the state, and the Least shrew is a fairly cosmopolitan species occupying most of Texas except for part of the Edwards Plateau and the Trans-Pecos (Schmidly 1994:55). It was collected during the pre-inundation survey (Table 10.2).

The tooth is a lower left first molar with the hypsodont shape and reddish-tipped coloration typical of *Cryptotis parva* teeth. The tips of both roots are missing, with old

breaks, and a small fragment of mandible is lodged between. The unidentified Soricidae mandible is broken off at both ends; the remaining part is 4.19 mm long. The posterior root of the M_2 is broken off in the socket, and some of the other alveoli have sediment or carbonate in them, indicating that some or all of the teeth became separated from the mandible before excavation. The only character that can be measured is the *mandibular body depth* at the midpoint of the second molar, 1.49 mm, which compares well with the body depth of 1.5 ± 08 mm reported by Graham (1976:Table 5) but is greater than comparative specimens *of C. parva* and *N. crawfordi* I have measured. All that can be definitely said is that the specimen does not belong to *Blarina*.

Shrews are hyperactive, with high metabolic rates and voracious appetites. They are mostly insectivores, foraging aboveground on insects, spiders, earthworms, centipedes, snails, and occasional vegetal matter. They are semifossorial and mostly nocturnal, spending daytime in nests or burrow systems, usually built under a rotting fallen log or flat rock. Least shrews are usually found by overturning logs, rocks, or debris. Several of the accounts in the biological literature explicitly state that *Cryptotis* can easily be caught by hand after being unearthed. Although they are aggressive and very cursorial, they have poor eyesight and hearing. Kilham (1954) remarks that a captured individual tried but could not bite him. There are also several accounts of least shrews being dug out by dogs (Hamilton 1934, 1944; Peterson 1936). They can also be captured in pitfalls.

Least shrews prefer areas with dense grass, sometimes with weeds or thorny thickets, but little or no tree canopy. Here they may share runways with hispid cotton rats, short-tailed shrews, rice rats, or harvest mice. These grassy areas may be upland prairie

or on creek floodplains if it is open. Unlike heteromyid rodents, least shrews seem to require some drinking water on a regular basis. Raun (1959:Table 1) recorded *Cryptotis parva* from postoak-blackjack oak woodland, wooded floodplain, and peat bogs at Palmetto State Park, and Blair (1952:237) found them common in mesic deciduous forest near Luling, but these reports seem atypical. In the pre-inundation survey at Coleto Creek Reservoir, none were trapped in bottomland forest, live oak forest, post oak forest, brush, brushy ravine, or improved pasture habitats; 12 individuals were collected in open pasture and five in brushy fencerow sites (eight in October, four in January, two in April, and three in August; Espey, Huston and Associates 1976:Tables 3-15 through 3-19). This indicates most of the Lissie and Beaumont terrace surfaces provide good *Cryptotis* habitat except where tree cover is heavy.

Cryptotis parva has one of the most widespread distributions of any of the bench deposit mammals, extending throughout the eastern US and eastern Plains as far north as latitude N43-44° and southward to the Isthmus of Panama. Over this extensive range, average annual temperatures range from about 8° C in the north to about 25° C in the tropics, where the average annual precipitation is over 398 cm. At its western limit in Colorado, annual precipitation is about 36.7 cm. Its western range limit has retracted since the Pleistocene due to Holocene drying (Hafner and Shuster 1996; Porter 1976).

Documented predators include barn, great horned, long-eared, short-eared, saw-whet, barred, and screech owls; red-tailed hawks, white-tailed kites, bobcats, swift foxes, red foxes, minks, coyotes, and copperhead snakes. The species has been found in low frequencies at a significant number of archeological sites, including the Guadalupe Bay site (Scott and Dukes 2002:Table 11-2), Swan Lake (Westgate and Prewitt 1987:Table

37), Big Lake (Raun and Laughlin 1972:Table 1), the Kyle site (Lundelius 1962:Table 4), the Hinojosa site (Steele 1986:133-134), various sites at Hog Creek Reservoir (Butler 1980:Tables 12.12, 12.13, 12.15), Wilson-Leonard (Balinsky 1998:Table 35-1) and 41 JK 91 (McGuff and Davidson 1978:Table 18).

Scalopus aquaticus (Eastern mole; Fig. 10.31, E; 10.37, A, E, F; 10.38, A, B; 10.39, A-H; 10.40, 10.41; 10.42, C)

Element	Ambient bone NISP	Hearth deposit NISP
mandible		3
P^3		1
P^4		2
M^2		1
M^3		1
incisor		5
P_4		1
M_1		1
M_2		1
M_3		1
skull fragments		3
left humerus	1	6
right humerus		4
left ulna		2
right ulna		5
left radius		2
right radius		2
left femur		1
right femur		1
left tibia		3
right tibia		1
carpal		7
carpal/metacarpal		9
first anterior phalanx		6
second anterior phalanx		7
third anterior phalanx		6
second posterior phalanx		1
first phalanx, unspecified		1
second phalanx, unspecified		1
third phalanx, unspecified		2

The Eastern mole (*Scalopus aquaticus*) is one of the most abundant taxa in the hearth deposit. Most of the remains come from the forelimb (Fig. 10.72), because this small insectivore has very robust, heavily developed forelimbs adapted for digging (Campbell 1939) and the forelimb elements preserve well. No vertebrae, ribs, scapula, clavicles, or pelvic components were recovered, unless they remain unrecognized in the unidentified small mammal category. This is the only mole in Texas. The species covers the entire eastern two-thirds of the state. Except in the Panhandle, the western range limit corresponds very crudely to about 56 cm of annual precipitation. These are small, compact mammals with massive, shovel-like forelimbs and a short tail. The eyes are covered with skin and essentially nonfunctional. The body is about 12.4 cm long. A scent gland on the belly is used as a marking device and is thought to render moles, like other insectivores, unpalatable to predators (Schwartz and Schwartz 1981:46, 48). Nationwide, females average about 60 g in weight, males about 100 g. Yates and Schmidly (1977:Fig. 8) recognize seven subspecies in Texas, including *Scalopus aquaticus alleni* in the region around Goliad County; this is the smallest subspecies in the entire state (Yates and Schmidly 1977:27-28), with a total length of 14 cm or less (Davis 1942:386).

The Eastern mole is fossorial, spending perhaps as much as 99% of its lifetime underground (Lowery 1974:86). Two kinds of tunnels are dug: 1) shallow, temporary insect-foraging tunnels about 2-3 cm under the surface; 2) more permanent deep tunnels 10-40 cm below the surface (Harvey 1976:436) with an underground nest (10-22 cm diameter) and latrine area. Home ranges are large (average about 0.74 hectares, up to a hectare or more for males). Schmidly estimates densities of four moles/hectare for most places in eastern Texas (Schmidly 1983:51).

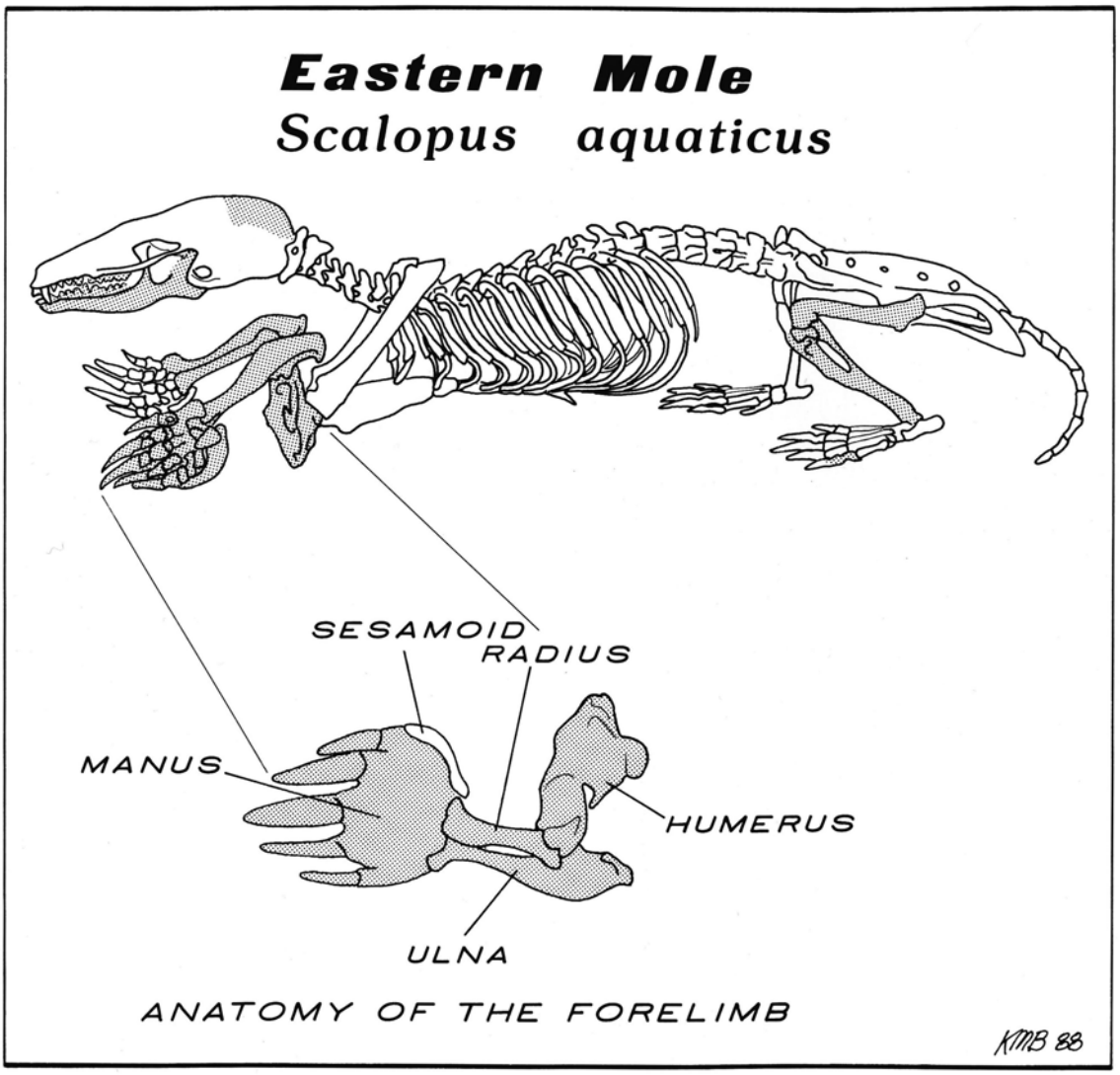

Figure 10.72. Eastern Mole Elements Recovered From the Hearth Deposit. Shading gives a rough indication of the elements recovered (skull fragments are tentative). The entire manus is shaded, but it has not been demonstrated that all parts were recovered.

Moles are detectable only when infrequently venturing aboveground or when actively displacing dirt. They are incapable of overland flight and can only escape by digging. Some references say Eastern moles are diurnal, others nocturnal, but in any case, activity is confined to the tunnel. Preferred foods are earthworms, grubs, insect eggs,

beetles, ants, centipedes, and small amounts of plant litter, occasionally other small animals (mice, voles, frogs, etc.; Hartman, Whitaker and Munsee 2000). The species was recorded during the pre-inundation survey (Table 10.2), but no information is given on density or habitat preference. Moles occupy floodplains if they are not subject to annual flooding, although Blair (1939) found them on recently flooded terrain in Oklahoma. McCarley (1952:104-105) found them both in floodplain forest and postoak-blackjack oak associations, but mostly in the latter. Floodplain soils seem to be preferred, as long as they are sandy and moist, not clay-rich or flooded, and edaphic conditions seem to be more important that ground cover, since moles may be found in habitat ranging from grassland to woodland. In Kansas, these moles show a definite preference for lowland sites under tree canopy and avoid the uplands (O'Neal and Kaufman 2004). In Willacy County, Texas, moles were abundant in deep sand with brush, prickly pear thickets, and mesquite savanna (Blair 1952:231-232). At Palmetto State Park (about 100 km northwest of Berger Bluff), Scalopus was found to be confined to the upland postoak-blackjack oak community, except for sandy outwash areas that lapped onto the floodplain of the San Marcos River (Raun 1959:160).

At Berger Bluff, it seems likely that the Eastern moles found there could have been obtained either on the floodplain or on adjacent higher sandy terraces. Although the Coleto Creek floodplain sediments are sandy now, at times during the Pleistocene the floodplain may have been somewhat too fine-grained for good mole and pocket gopher habitat, in which case higher levels of soil moisture might have allowed these populations to move up onto the adjacent terraces. In fact, populations may have shifted topographic position repeatedly as prevailing grain size in the valley varied (see Chapter 4). None of the krotovinas seen during excavation of the bench deposits are thought to belong to

Scalopus, in part because the sediments were probably too clay and silt-rich for suitable substrate most of the time. Referring to *Scalopus aquaticus* on the Aransas Peninsula, J. A. Allen wrote, "Moles are very numerous all over the peninsula, perhaps the most common of any of the small mammals…. They are particularly active after a rain…. Mole runways are very common even in parts of the country where the soil is very poor, apparently nothing but sand…. But they are most common where the soil is more or less damp…. They appear also to be more active in the fall, spring and winter months than in summer…. The position selected for the nest is several feet below the surface, and always in a hard place to get at, being generally under a clump of bushes or a tree" (Allen 1894:186-187).

Like other fossorial species, the Eastern mole has a wide range of climatic tolerance. It is distributed widely throughout the eastern US; its southern limits are in northern Tamaulipas, about 70 km south of the Rio Grande, perhaps limited by high burrow temperatures. It extends to the north as far as central Minnesota, into Massachusetts, and southeastward nearly to the tip of Florida, westward to Wyoming. Over this range, mean annual temperatures vary from about 2° C to 24° C and mean annual precipitation from about 26 cm to about 146 cm.

Moles have few natural predators and low mortality rates. Owls (especially barn owls) are probably the chief predators, but hawks, skunks, coyotes, red foxes, badgers, and possums occasionally prey on them. They are absent from most predator diet studies, and when present rarely account for more than one or two percent of the diet. Ethnographic accounts of humans preying on moles are scarce (see Durán 1964:11). A

few groups in the borderlands region are known to have occasionally eaten moles of the genus *Scapanus*. Among the Pima Bajo,

> Pedro Estrella Tanori recalled that during his childhood moles were eaten. They were drawn, skinned, spitted, and roasted (Pennington 1980:201-202).

Among the Tepehuan,

> *Tuvoki* is a term applied indiscriminately to a small black mole (*topo*) and to a large gray gopher (*tuza*)…. Gophers and moles are caught in steel traps (borrowed or traded from the mestizos), or when found in the open, they are killed with bows and arrows. However, the Indians state that there is little opportunity for surprising gophers or moles in open country since the animals can detect the scent of human beings for some twenty or thirty feet. Once killed, they are skinned, drawn and roasted on a spit or boiled with scraps of any other meat that may be available (Pennington 1969:124-125).

Trippel (1889:575) recorded that moles were eaten by the Yuma of California and Arizona. *Scalopus aquaticus* occurs widely in the paleontological and archeological record of Texas. It is widespread in Pleistocene deposits and appears in some areas, such as Edwards County (Dalquest, Roth and Judd 1969:222) where it is absent today. It is found at the Avenue site in Austin (Lundelius 1992:334), Friesenhahn Cave, Hall's Cave, Cave Without a Name, Miller's Cave, Zesch Cave, Longhorn Cavern, Carroll Creek, Howard Ranch, as well as the Jones-Miller site in Colorado.

It is even more widespread in archeological deposits. Locally, it is found in the upper deposits at Berger Bluff as well as at 41 GD 21, the Burris site, and the Smith Creek Bridge site. Table 10.26 gives some examples of archeological occurrences in Texas selected without regard to time period or region. Parmalee (1975) also reports on a specimen from Tennessee with cutmarks.

Table 10.26. Some Archeological Examples of *Scalopus aquaticus* in Texas.

Site	Reference
Smith Creek Bridge	Froelich (2002:Table 91, 96)
41 GD 21	Butler (1979:Table 16)
41 GD 21A	Fox, Black and James (1979:Table 3)
Burris	Shaffer (n.d., Table 1)
Buckner Ranch	Nash (2001:Appendix 3)
Guadalupe Bay	Scott and Dukes (2002:Table 11-2)
41 CL 70, CL 59	Weinstein (1992:Table 7-20, 7-29)
41 JK 66, JK 74, JK 179, JK 91	Winans (1981:Table III-1)
Big Lake	Raun and Laughlin (1972:Table 1)
Ingleside Cove	Story (1968:Table 14)
Hinojosa	Steele (1986:Table 10)
Loma Sandia	Hellier *et al*. (1995:Table 113)
41 MC 292	Steele and Assad Hunter (1986:Table 39; page 485)
Allens Creek sites	McClure (1987:9)
Alabonson Road	Baker *et al*. (1991:Table 33)
41 CH 46	Dillehay and Davidson (1975:Table 9)
41 CH 172	Dillehay and Davidson (1975:Table 11)
41 CH 252	Shaffer (1995:Table E-2)
41 CH 63	Weinstein *et al*. (1988:Table 6-5)
Crawford	Hunter (1988:311, Table 53)
Taddlock	Bruseth and Perttula (1981:Table 7-3)
Williams	Parmalee and Opperman (1983:Table 1)
Levi Rockshelter	Alexander (1963:Table 1)
Kyle Rockshelter	Lundelius (1962:Table 4)
Bear Creek Shelter	Lynott (1980:table 12)
Aubrey	Yates and Lundelius (2001:Table 8.1, 8.3)
Lake Theo	Harrison and Killen (1978:Table 4)
Roper	Duffield (1970:Appendix D)

Geomys attwateri or *Geomys personatus* (Attwater's or Texas pocket gopher)
Geomys sp. (pocket gopher, unidentified; Figs. 10.29, I, J; 10.37, D; 10.39,I-L; 10.46, F)

Element	Ambient bone NISP	Hearth deposit NISP
maxilla	2	
mandible	8	
I^1	2	
incisor, lower	3	
incisor, unspecified	2	
P_4		1
molar, upper	1	1
M_3	1	
molar, unspecified	2	
cheek tooth	1	
left humerus		4
right humerus		1
humerus, unspecified	1	
right scapula		1
left femur		5
right femur		2
metacarpal		2
caudal vertebra		2

The taxonomy of pocket gophers in Texas has been extensively revised in recent years, in part as a result of RNA and morphometric studies (Jolley, Honeycutt and Bradley 2000; Mauk, Houck and Bradley 1999). Cabaniss originally identified most of this material simply as *Geomys* sp. and some was identified as "*Geomys bursarius* or *Geomys personatus*." As currently understood, there are two pocket gophers with an overlapping distribution in the region around Berger Bluff: Attwater's pocket gopher along the central coast (where it is endemic), and the Texas pocket gopher (*G. personatus*) on the Rio Grande Plain, extending northward into Goliad County (subspecies *G. personatus fallax*). Both species, then, are recorded for Goliad County. *Geomys bursarius* is listed for the pre-inundation ecological survey (Table 10.2), but no one has re-examined those specimens to see whether they should be reclassified as *G. attwateri* or *G. personatus*.

Based on current knowledge of gopher taxonomy, I suspect all the Berger Bluff material is probably the endemic *Geomys attwateri*, but that cannot be demonstrated without further detailed studies. The material that Cabaniss originally labeled as "*Geomys bursarius* or *Geomys personatus*" should probably be relabeled as "*Geomys attwateri* or *Geomys personatus*." Much of the gopher material consists of mandibles (often invaded by carbonate) with partial dentition, or easily recognized but loose incisors. The ambient fauna (N109 E96, 92.70-92.65 m, lot B-158) contains two teeth from a subadult. Immature gophers are vulnerable when dispersing overland, above ground (Williams and Cameron 1984).

Attwater's pocket gophers weigh about 163 g for adult males and 131 g for females (Williams and Cameron 1991:1) and are about 22 cm in total length. Texas pocket gophers are larger, weighing up to 400 g, and 30-32 cm in length (including tail; Schmidly 2004:341). Pocket gophers are fossorial generalist herbivores (Williams and Cameron 1986). They prefer moist, sandy soil, and the postoak parkland on the Beaumont and Lissie terrace surfaces in the Coleto Creek Reservoir area provides ideal habitat. Gopher burrows and tunnels were in evidence throughout the area surveyed by archeologists before the reservoir was built, and much of the surface evidence was found atop gopher mounds (see Fox, Black and James 1979). The comments already made about Eastern moles apply as well to gophers: floodplain deposits should provide good gopher habitat as long they are not flooded or otherwise saturated, but at times in the late Pleistocene, the floodplain sediments might have been too silty or clay-rich for gophers, and populations might have shifted out of the valley to adjacent terraces. Burrows average about 18 cm in depth, deepening to about 20 cm in the dry summer months

(Williams and Cameron 1990:Fig. 1). Individual burrow systems cover about 200 m and have a total length of about 90 m in a circuitous pattern (Cameron *et al*. 1988:Fig. 1), but occupied burrows can be recognized by evidence of fresh dirt. Gophers are active in all hours of the day, but largely confined to the burrows.

Gopher remains are common in archeological sites, where they are invariably designated "intrusive" and then disregarded, even though there is an extensive record of gophers being snared, hunted, or flooded out for human consumption. Most of the ethnographic records probably pertain to *Thomomys* or other genera found in the borderlands region. Gophers were eaten by the Yokuts (Gayton 1948:75), Wappo (Driver 1936:186), Wintu (DuBois 1935:13), Plains Cree (Mandelbaum 1979:69), Kutenai (Turney-High 1941:41), Chilula (Lake 1982:66), Diegueno (Cuero 1970:56), Yuma (Trippel 1889:575), Mohave (Stewart 1947:83), Pima (Russell 1908:82), Tepehuan (Pennington 1969:124-125), Chichimeca-Jonaz ("tusa," Driver and Driver 1963:61), Owens Valley Paiute (Steward 1933:255), Northern Paiute (Fowler 1989:24), Western Shoshone, Panamint, Nevada and Utah Southern Paiute, Western Ute, Southern Ute (Fowler 1986:80), Santa Clara Pueblo Indians (Hill 1982:54), and many other groups. Snaring, deadfalls, archery, and flooding of burrows with water are methods mentioned in the ethnographies. The Tarahumara used springpole snares (Bennett and Zingg 1935:117), while the Cahita used a springpole snare with a unique ceramic housing (Beals 1943:Fig. 1). The contemporary Yucatec Maya still practice springpole snaring of hispid pocket gophers (*Orthogeomys hispidus*) for human consumption, a process that is described in good detail by Hovey and Rissolo (1999). Most archeologists, however, choose to remain blissfully oblivious to this panorama of historical data (however, see Shaffer 1992b).

Chaetodipus hispidus (Hispid pocket mouse; Fig. 10.42, A; 10.45, A; 10.46, C)
cf. *Chaetodipus hispidus*
Chaetodipus/Perognathus sp.

Element	Ambient bone NISP	Hearth deposit NISP
mandible		3
upper incisor	1	
M^1		1
M^2		1
P^4		2
P_4		3
M_1 or M_2		1
M_1		1
M_2		1
unspecified molar fragments		2
left femur	1	
left tibia		1
right tibia		2

The Hispid pocket mouse (*Chaetodipus hispidus*, formerly *Perognathus hispidus*) occupies nearly all of Texas, including the Berger Bluff area. Merriam's pocket mouse (*Perognathus merriami*) occupies most of the western two-thirds of the state and occurs in Bee County but apparently has not been recorded in Goliad County (Schmidly 2004:353). No pocket mice of any kind were trapped in the pre-inundation ecological survey, although some remains were found in a raptor pellet collected during the Flume No. 3 survey (Fig. 10.53). This mouse ranges throughout the Plains as far north as southern North Dakota and as far south as central Mexico (Paulson 1988:Fig. 3). Most of the identified elements are from the dentition. Among the premolars and molars from the hearth deposit, two are heavily worn and four slightly worn, suggesting at least two individuals of differing ages.

Pocket mice (and kangaroo mice) are the mouselike counterparts of kangaroo rats, the other members of the family Heteromyidae. Like them, they have cheek pouches,

oversized hind limbs and relatively long tails, and are fossorial, solitary, nocturnal rodents with relatively long lifespans. They are generally dormant in winter. These are medium to relatively large mice with a body length of about nine to 11-12 cm, with a tail roughly the same length. Adults weigh about 30-47 g (average about 35 g).

Pocket mice are nocturnal seed foragers, transporting the seeds in cheek pouches. Alcoze and Zimmerman (1973) found that seeds made up 81% of their diet in Fisher County; insects made up 13.9% of the spring diet and 1.2% of winter diet. According to Dalquest and Horner (1984:115), these mice, like kangaroo rats, can subsist without drinking water. They have a "quadrupedal bounding gait" (Price and Waser 1985:211) rather than the bipedal hopping of kangaroo rats. They are said to be aggressive, yet when kept in confinement become tame. Hispid pocket mice apparently tolerate denser, less friable soils than kangaroo rats (Blair 1952:241; Alcoze and Zimmerman 1973:907; Paulson 1988:3). Dalquest and Horner (1984:114) observe that burrow entrances may be plugged with dirt during the daytime if the burrow is in sandy soil, but left unplugged if in harder soil. Schmidly (2004:358) says that the burrows resemble 1-inch auger holes bored straight into the ground. Bailey (1971:280) remarks that burrows are hard to locate.

> Burrows average about an inch in diameter and descend in a vertical drop for several inches, then in a more gentle incline or spiral to a depth of a foot or more. Shallow burrows, like those of the silky pocket mouse, are sometimes constructed in sandy or gravelly soil…. There may be several entrances to a burrow, but usually there are only two or three (Dalquest and Horner 1984:114).

Hispid pocket mice have a large continental range and occupy a variety of campestral habitats, but the most significant habitat type is shortgrass prairie, often with a significant percentage of forbs. Many studies have shown that these mice prefer somewhat denser vegetation than is tolerated by kangaroo rats. Where *Dipodomys ordii*

may occupy nearly bare disturbed ground, *Chaetodipus hispidus* may prefer terrain where disturbance has ceased and rank weedy vegetation is covering the area. Sand dunes, riparian habitats, and closed-canopy woodlands are usually avoided, however. In Texas, these mice are common on the coastal prairie. The pocket mice in the bench deposits may have originated in the grassy postoak parkland on the Lissie and Beaumont terrace surfaces, though not in areas with closed canopy. Raun (1959) at Palmetto State Park and McCarley (1952:107) in Oklahoma found them in similar habitat. Hispid pocket mice occur in low densities. In Texas, Hay (1951:16) measured home ranges yielding a density of about 1.50/hectare for females and 2.15/hectare for males. In Kansas and Oklahoma, densities have been estimated at around 0.30-0.60/hectare. In a study in Webb County, Windberg (1998) found the species spread evenly in low densities across a variety of grass and shrub habitats.

Chaetodipus hispidus is a very eurytopic species. It occupies nearly the entire state, from the arid Trans-Pecos to the humid northeastern corner, and is absent only from deep southeast Texas (Schmidly 2004:359), and obviously is not greatly limited by precipitation or temperature. It can tolerate fairly arid conditions (annual precipitation 22.7 cm) to mesic (137 cm) and mean annual temperatures ranging from 5.17° C in the north to 23.3° C in the south. It is expected to show less response to global warming than other rodent species (Cameron and Scheel 2001:668).

The chief predators are owls (especially barn owls) and western diamondback rattlesnakes. Pocket mice (*Perognathus* spp.) were eaten by the Owens Valley Paiute, Panamint, Western Shoshone, Utah and Nevada Southern Paiute, Chemehuevi, Southern Ute, and Western Ute (Fowler 1986:80). Hispid pocket mice are fairly common in both

paleontological and archeological deposits in Texas. About half the archeological sites are open ones. In keeping with the biological traits of the species, it occurs widely but in low frequencies. Some examples are Lubbock Lake (Johnson 1987:Table 7.1), Big Lake (Raun and Laughlin 1972:Table 1), 41 NU 103 (Steele and Mokry 1985:Table 2), 41 MC 296 (Steele and Hunter 1986:492), 41 FB 32 (McClure 1989:19), Loeve-Fox (McDonald 1974:Table VIII), Kyle (Lundelius 1962:Table 4), L. E. Robertson Shelter, Five Goat Shelter, the Dam site, Opilionid Shelter, and Windy Shelter (Butler 1980:Tables 12.13 through 12.17), Taddlock (Bruseth and Perttula 1981:Table 7-3), 41 DL 147 (Yates 1982:Table II-2), the Rainey site (Henderson 2001:Table 13, 15), Baker Cave (Douglas 1970:Table 1), Seminole Sink (Rosenberg 1985:205), Allen Ranch Rockshelter (Green and Green 1974:Table 4), and Canyon City Club site (Duffield 1970:Table 31, 32). There are also many more reports that simply list "*Perognathus* sp."

Heteromyidae (unidentified pocket mouse or kangaroo rat)
Hearth deposit
1 proximal tibia (juvenile)
1 mandible fragment with incisor

Dipodomys compactus or *Dipodomys ordii* (Gulf coast or Ord's kangaroo rat)
Dipodomys cf. *D. ordii*
Dipodomys sp.
Ambient fauna
1 left proximal tibia (N109 E96, 92.35-92.30 m, lot B-139)
1 left distal tibia (juvenile, Feature 7 fill; N109 E96, 92.35-92.30 m, lot B-140)

Hearth deposit
1 P^4 1 unspecified molar
1 M^2 1 deciduous P_4
1 M^3

As in the case of several other taxa, the mammalian taxonomy of kangaroo rats has been revised since the original identifications were done. All of this material was originally identified either as *Dipodomys* cf. *D. ordii* or just *Dipodomys* sp., but the

kangaroo rat now recognized in the region is the Gulf Coast kangaroo rat, *Dipodomys compactus* (Schmidly 2004:365) recently elevated to specific status, and it seems likely that all the Berger Bluff material belongs to this species, based on current knowledge of geography (Baumgardner and Schmidly 1981:Fig. 11). As currently recognized, Ord's kangaroo rat (*Dipodomys ordii*) occurs in south Texas, but no closer than the counties of Atascosa and McMullen (Schmidly 2004:371). The two species are sympatric over a large part of south Texas and are closely related (Baumgardner and Kennedy 1994:Fig.1; Carrasco 2000:Fig. 4), differing mainly in minor details of the head and tail (Baumgardner 1991:1). Because the revision is recent, the ecological and archeological literature has much more information on Ord's than on Gulf Coast rats. McCoig (1983) has done a thesis on Gulf Coast rats from Padre Island, but I have not seen it. No kangaroo rats were found in the pre-inundation ecological survey. Schmidly (2004:365) maps records of *D. compactus* in Bee County and Gonzales County, but not the counties of Goliad, Refugio, Victoria, De Witt, or Karnes. There appears to be at least one juvenile in both the hearth deposit and the ambient fauna. The breeding cycle is little known, but other species in the genus are polyestrous and breed year-round. The deciduous P_4 in the hearth deposit indicates a juvenile. McCulloch (1961:159) says deciduous teeth of *D. ordii* indicate an age less than two months, but he found them in individuals trapped as late as mid-November. Dalquest and Carpenter (1986:252) say that even the youngest individuals they trapped had some wear on these teeth, but the hearth deposit specimen is unworn, and must be from a very young individual.

Along with pocket mice, kangaroo rats are members of the Heteromyidae. The Gulf Coast kangaroo rat (subspecies *D. compactus sennetti*, Baumgardner and Schmidly 1981:Fig. 11) covers most of the Rio Grande Plain. It occupies areas with sandy soil and

sparse vegetation: mesquite savanna, post oak-blackjack oak parkland (Baumgardner 1991:3). Baumgardner and Schmidly (1985) found that where *D. compactus* and *D. ordii* lived sympatrically in Jim Hogg County, *D. compactus* occurred adjacent to disturbed sites, but where the species were separated, *D. compactus* lived in both disturbed and undisturbed habitats. This suggests the Gulf Coast kangaroo rat has some affinity for open, disturbed areas (such as revegetating burned areas) and can move into them when in competition with other species. Near Berger Bluff, this species was perhaps associated with pocket mice, Northern grasshopper mice, and woodrats in the grassy postoak parkland on the Lissie and Beaumont terrace surfaces, provided it was not too heavily vegetated at the time, and had some bare ground for dust bathing. *Dipodomys ordii* has been recorded from floodplain habitats in western states (Miller, Wilson and Andersen 2003), but these are probably less vegetated than Coleto Creek.

These kangaroo rats are solitary, territorial, and nocturnal, remaining in their burrows (often with plugged entrances) during the day. Locomotion is by hopping, hence the name. These are medium-sized rats, weighing about 44-60 g, with large hind feet (about 3.6 cm long) and long tails (about 12 cm long). Ord's rats average about 60 g. The stance is bipedal, and kangaroo rats can jump up to 1.2 m high and 1.8 m horizontally (Dalquest and Horner 1984:117), leaving paired hind footprints behind. The related species *D. merriami* and *D. microps* have top speeds of 32 and 21 km/hour, respectively. Bailey (1971:267) describes *Dipodomys ordii* burrows:

> In many cases, the burrows enter the ground under the edge of cactus or some of the low bushes or spreading plants that seem to offer them shelter and protection, but in other cases they are in the most exposed and unprotected situations. A sand bank or sloping dune is a favorite site for the burrow, which always enters the ground at a nearly horizontal position, often with the doorway slightly lower than the main shaft of the burrow. They do not, as some other species, build mounds

> over their dens, but the burrows are often in groups of three or four or even more, radiating from a common underground center. For the size of the animal the burrows are rather large, and at times considerable earth is thrown out, usually to quite a distance from the entrance. Part of the burrows are closed during the day, apparently to keep out snakes and other enemies, but some are always left open, and it is probable that the closed burrows are the ones occupied.

Entrances are large, perhaps 7.5-9.0 cm in diameter, approached by runways or beaten paths. Like grasshopper mice, kangaroo rats are dust bathers, rolling in the sand to control secretions produced by sebaceous glands. According to Findley (1987:83), dust-bathing sites tend to be traditional and communal. Presence of open ground with loose sand is therefore an important part of habitat selection. Kangaroo rats are granivorous, eating seeds from a variety of forbs, grasses, and shrubs (Alcoze and Zimmerman 1973:905, 906). They can subsist while drinking little or no water, obtaining some moisture from seeds, thanks to efficient kidneys, skin oil, and nocturnal habits. The climatic tolerance of the Gulf Coast kangaroo rat is somewhat restricted, simply because its range is mostly confined to the Rio Grande Plain. Average annual temperatures vary from about 20.6-23.3° C and annual rainfall from 51-84 cm.

Regarding ease of capture by humans, Findley remarks "It is possible to slowly approach a foraging kangaroo rat and then with a quick pounce to catch it by hand. If you miss the first time, however, you are in for a wild chase. Even newly captured *Dipodomys* are relatively gentle, and with a little care they may be handled quite easily…." (Findley 1987:81). Several other accounts also mention capturing *D. ordii* or *D. merriami* by hand, and add that the rats can be routed out of their burrows by stamping on them. Davis (1966:172) remarks that "they are timid and make interesting pets. Also, their flesh is white, tender, and as delicious as frogs' legs or chicken." Kangaroo rats were eaten by the Seri (Malkin 1962:9), Lipan Apache (Dennis and Dennis 1925:128, quoted earlier),

Nomlaki (Goldschmidt 1951:401), Panamint Shoshone (Coville 1892:352), Northern Paiute (Fowler 1989:24), Washo, Owens Valley Paiute, Western Shoshone, Nevada and Utah Southern Paiute, Western Ute, Southern Ute, Northern Ute, and Eastern Shoshone (Fowler 1986:80). Among the Walapai, "The kangaroo rat, ohu'l, which only comes out after dark, was obtained by building a fire beside his hole. When he ran out he was killed. Practically all rodents, including mice, [i]wê', were killed and eaten whenever the opportunity presented itself" (McKennan 1935:64). The following early account of nocturnal rodents with cheek pouches comes from Baja California and probably refers to kangaroo rats and pocket mice:

> Aún más regalada que la carne de las ardillas es para los indios la de las ratas, que dicen ser muy tierna y blanca; y por eso cuando tienen ocasión de matar alguna, no la pierden; mas como ellas poco andan de día, no tienen los indios ocasión de matar muchas, como quisieran. En todas partes, poblados y despoblados, hay grande abundancia de ratones, con las propiedades que tienene en todas partes. Lo particular que se halla en éstos de la California es el tener dos bolsas más abajo de las orejas, y cerca de la boca, una en cada lado… (del Barco 1973:21-22).

Kangaroo rat remains are infrequently found in archeological sites, but any that have been found in south Texas have probably been listed as *Dipodomys ordii*. *D. ordii* is reported from Lubbock Lake (Johnson 1987:Table 7.1); *Dipodomys* sp. is reported from the Aubrey site (Yates and Lundelius 2001:Table 8.1, 8.3) and Hinds Cave (Lord 1984). I have already mentioned the *Dipodomys* remains found in coprolites from Tamaulipas (Marsh 1964:52-53) and Wilke (978:82) has reported bone fragments of immature kangaroo rats (probably *D. merriami* or *D. deserti*) in two human coprolite samples from Myoma Dunes in California. Teeth of *Dipodomys heermanni* are reported in one coprolite from Bamert Cave, California (Nissen 1973:67).

Onychomys leucogaster (Northern grasshopper mouse; Fig. 10.73)
Ambient fauna (N110 E102, 92.00-91.95 m), from matrix sample
1 M_1

This species is represented only by a single lower right first molar (Fig. 10.73) found at the base of stratum 2A, at about the same level as Feature 6, and probably just above the extensive zone of phreatic carbonate in that unit. Since it came from the matrix sample, it would have been found in the southwest corner about a meter away from the feature.

Grasshopper mice are insectivorous cricetid rodents. The Northern grasshopper mouse is a xeric-adapted mouse occupying south and west Texas. Schmidly (2004:422) indicates it has been collected from the counties of Bee and Refugio, but not Goliad. None were collected in the pre-inundation ecological survey. In its continental distribution, it is clearly an arid land rodent, occupying vast reaches of the shortgrass plains and basin and range province of the desert West, into northern California and Washington. Its eastern limit roughly corresponds to the eastern limit of shortgrass prairie, approximately following the 71 cm annual precipitation isohyet. To the west, the limit is the Sierra Nevada rainshadow. These mice seem not to be limited by aridity, but by heavier rainfall and ground cover. Refugio County seems to be the most mesic part of its entire range.

These small mice weigh about 27-46 g (average about 35 g). They are nocturnal (Stockrahm *et al*. 1995:17), aggressive and strongly territorial, preying on insects and other rodents. The digestive tract in other species is adapted to handle large amounts of indigestible insect chitin. In laboratory experiments, grasshopper mice readily kill all

kinds of smaller sympatric rodents (*Peromyscus, Perognathus, Microtus, Sigmodon, Reithrodontomys*; McCarty 1978:4) and have been observed killing *Dipodomys ordii* (Rebar and Conley 1983:984; Ruffer 1964:27). Dietary studies suggest about 1-9% mammal or reptile consumption. In wintertime, they may partly switch to seeds. Grasshopper mice are active in early evening, least active under a full moon.

As a carnivore, Northern grasshopper mice are higher in the food chain than other rodents and are less common, although Blair (1952:243) reported them "surprisingly common at times in some localities in the Tamaulipan province." Studies in South Dakota found densities of 0.50-0.55 individuals/hectare (Wilhelm, Choate and Jones 1981:31-32). Home ranges are large (2.3 hectares in one study; McCarty 1978:3). They have four burrow types: 1) nest burrows, average maximum depth 14 cm with two entrance tunnels; 2) retreat burrows, depth 20 cm; 3) small cache burrows for seeds; 4) miscellaneous burrows (latrines, signpost burrows used for dust bathing, etc.; Ruffer 1964).

Northern grasshopper mice are found in sandy areas, shortgrass or mixed grass prairie, dune areas, or open brushland (Ruffer 1964; Wilhelm, Choate and Jones 1981:20; Flake 1973:636-637; Genoways and Jones 1972) and are fairly cosmopolitan in habitat choice. In Martin County, Ramsey and Carley (1970) found them associated with *Neotoma micropus* and *Dipodomys ordii* in areas with fine sandy loam and heavy mesquite growth. Blair (1954:252) found them mostly restricted to sandy soils. Some biologists have suggested they prefer disclimax communities with bare, disturbed ground and weedy pioneer annuals such as ragweed. Egoscue (1960:101) suggests their distribution may be controlled more than anything else by the availability of dry ground

for dust bathing. At Berger Bluff, this species would have been found in association with heteromyid species (*Dipodomys* and *Chaetodipus*) in some open sandy upland habitat, possibly at some distance from the site.

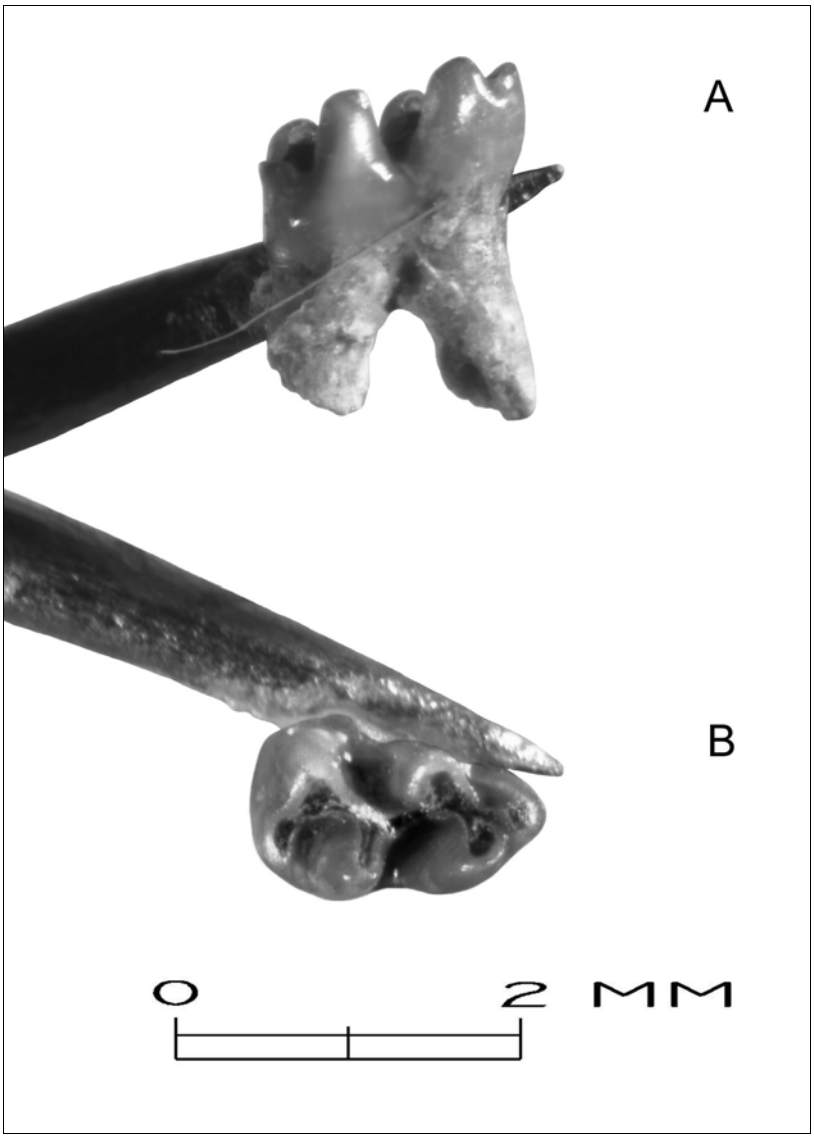

Figure 10.73. Grasshopper Mouse Molar From the Hearth Deposit. A, lower left first molar of *Onychomys leucogaster* mounted on the tip of a common steel straight pin; B, occlusal surface of same specimen; orientation uncertain. Unit 2, Feature 5 and surrounding surface, lot B-149.

Like the heteromyids, even though grasshopper mice are inherently aggressive, they are said to be docile when handled by humans (Bailey 1971:139). There seems to be little mention of them in the ethnographic record, although Fowler (1986:80) says that *Onychomys* spp. were eaten by natives of the Great Basin. A fairly large sample of *Onychomys leucogaster* appears in Late Pleistocene deposits at Schulze Cave in Edwards County (Dalquest, Roth and Judd 1969:Table 1), although none are recorded in the modern Edwards County fauna (Schmidly 2004:422).

Although not abundant, Northern grasshopper mice are more commonly reported in the archeological record from Texas than might be expected (Table 10.27). The species was also found in the upper deposits at Berger Bluff (Fox, Black and James 1979:Table 3).

Table 10.27. Some Archeological Examples of *Onychomys leucogaster* in Texas.

Site	Reference
Petronila Creek	Lewis (1988)*
Loyola Beach	Smith (1986:Table 25)*
41 WY 60	Rawn-Schatzinger (1981:Table 25)
Kyle	Lundelius (1962:Table 4)
Mason Ranch	Benfer and Benfer (1981:20)
Cobb-Pool	Peter and McGregor (1988:Table 9-19)
Cueva Quebrada	Lundelius (1984:467)*
Baker Cave	Hester (1983:Table 3)
Hinds Cave	Lord (1984:Table 8)
Seminole Sink	Rosenberg (1985:205-206)
Bonfire Shelter	Lorrain (1966:Table 14)*
Pratt Cave	Lundelius (1979:250)
West Cave	O'Laughlin (1977:Table C5)**
Deadman's Shelter	Schultz and Rawn (1978:Table 49)
Lubbock Lake	Johnson (1987:Table 7.1)
41 TG 91	Creel, Scott and Collins (1990:Table 3)

* Reported as *Onychomys* sp. or *Onychomys* cf. *O. leucogaster*.

** Possibly *Onychomys arenicola?*

Peromyscus cf. *P. leucopus* or *P. maniculatus* (cf. White-footed mouse or Deer mouse)
Hearth deposit (N113 E98, 92.443-92.400 m, lot B-106)
1 proximal femur

This species is represented only by a proximal fragment of the right femur in the hearth deposit. Deer mice (15-32 g, grasslands or brush) and White-footed mice (15-25 g, average 22 g, woodlands) are sympatric over nearly all of the state of Texas (Schmidly 2004:404, 406). Only the White-footed mouse, *P. leucopus*, was trapped during the pre-inundation ecological survey (Table 10.2). The single femur fragment is not enough to distinguish between these two species. Fossil *Peromyscus* species are difficult to distinguish even when dentitions are available for study (Martin 1968).

Regarding *Peromyscus leucopus*, Schmidly says,

> In the main, these mice are woodland dwellers, a trait best illustrated along the western border of their range, where they are restricted almost entirely to creek and river bottoms. As one progresses eastward, the mice are found in a progressively greater variety of habitats. In east-central Texas, they are most abundant in bottomlands, less so in post oak uplands, and almost completely absent from prairie lands…. They are adept at climbing and often den in hollow trees out of danger from overflow waters. In areas not subject to inundation, they live in dens under logs, in stumps, brush piles, burrows, or buildings.
>
> *Peromyscus leucopus* mostly is nocturnal, and it forages for seeds, mesquite beans, berries, fruits, nuts, and insects at night. In addition, carrion is sometimes consumed. A considerable amount of the foraging activity of the white-footed mouse occurs in brushy vegetation (Schmidly 2004:402-403).

As Table 10.28 shows, nearly all the White-footed mice trapped in the pre-inundation survey came from brushy areas, evidently on the Beaumont terrace surface adjacent to the valley slope (Espey, Huston and Associates 1976:Fig. 2-2) in areas with huisache, mesquite, and some post oak. Only one was trapped in creekbottom woodland, so evidently the local White-footed mice have habitat affinities more akin to Deer mice than is usually the case. In other parts of the country, White-footed mice are more typical

of hardwood forest and Deer mice of grassland and abandoned fields (Brown 1964:Table 1; see also Lackey 1978; Kaufman *et al*. 1983). Elsewhere, they may be found both in floodplain forest and adjacent upland forest (Batzli 1977; Blem and Blem 1975; Frydendall 1961). Grant, Carothers and Gidley (1985:Table 1) found a mean density 6.45 individuals/hectare (range, 0-29) in an old field in post oak savanna near College Station.

Table 10.28. Small Mammal Trapping Data for Coleto Creek Reservoir.

Habitat	*Cryptotis parva*	*Peromyscus leucopus*	*Sigmodon hispidus*
Open pasture	12	0	0
Brushy pasture	5	4	4
Brush piles	0	12	0
Upland forest	0	0	0
Lowland forest	0	1	0
Total:	17	17	4

Source: Espey, Huston and Associates (1976:Table 3-19).

Regarding Deer mice, Schmidly says,

> These mice occupy a variety of habitats, ranging from mixed forests to grasslands to open, sparsely vegetated deserts. In Texas, they usually inhabit grasslands or areas of open brush, especially where weeds and grasses offer concealment and a source of food….
>
> They are almost strictly nocturnal…. They live in underground burrows, in brush piles, or in crevices among rocks. The burrow is simple in design and usually consists of two or three short branches converging from as many surface openings to a single tunnel that slopes steeply to the globular nest chamber, which is 7-10 cm in diameter.

These are nocturnal mice with large eyes and relatively rotund bodies about 9-10 cm long. Average maximum running speed for Deer mice is 13.4 km/hour (Djawdan and Garland 1988:Table 1). Pettus and Robinson (1957) report catching three Deer mice by hand during the evening in Aransas County.

Species of *Peromyscus* are mentioned only sparingly in the ethnographic literature, in large part because they are lumped indiscriminately with vague categories of "field mice" that cannot be assigned to biological taxa. For example, the "dormice" mentioned by Solís might well be *Peromyscus*. According to Bennett and Zingg (1935:119), the Tarahumara trap *Peromyscus dificilis* (in pitfalls?), then singe and roast them on a spit. Fowler (1986:80) says *Peromyscus crinitus* was eaten by many native groups in the Great Basin. The Northern Paiute ate *Peromyscus truei* and *Peromyscus maniculatus* (or possibly *Reithrodontomys*; Fowler 1989:24-25). Coville (1892:352) says that "white-footed mice" were eaten by the Panamint Shoshone. Good evidence of *Peromyscus* consumption comes from coprolite and mummy studies. *Peromyscus* was found in the Skiles mummy (Turpin, Henneberg and Riskind (1986:307) and in coprolites from Hinds Cave (Williams-Dean 1978:197), Baker Cave (Sobolik 1988:Table 15), Salts Cave (Watson 1969:55), and Hoy House at Mesa Verde. Osteological remains are also fairly widespread, usually in low frequencies, in Texas archeological deposits, for example the Smith Creek Bridge site (Froelich 2002:Table 96), 41 CL 70 and 41 CL 59 (Weinstein 1992:Table 7-20, 7-29, 7-30), Loma Sandia (Hellier, Steele and Hunter 1995:Table 113), Baker Cave (Douglas 1970:Table 1), Hinds Cave (Lord 1984:Table 8, 13), the Rainey site (Henderson 2001:Table 1, 2), Wilson-Leonard (Balinsky 1998:Table 35-1), and Lubbock Lake (Johnson 1987:Table 7.1).

Sigmodon hispidus (Hispid cotton rat)
Ambient fauna (N109 E103, 92.65-92.60 m, lot B-11)
1 M_2
1 M_3

The only evidence of cotton rat identified so far is a carbonate concretion with remnants of the mandible and lower second and third molars, from the ambient fauna. The Hispid cotton rat is a medium-sized rat (80-150 g) with a body about 16 cm long. It occupies the entire state and is a generalist herbivore, feeding on grasses, seeds, and occasionally insects or animal matter. Most of the diet (61-92%) consists of monocots, but some dicots are eaten (Randolph, Cameron and Wrazen 1991; Kincaid and Cameron 1982:Table 1). On the Texas coastal plain, it is a grassland rodent, found chiefly in prairie and mesquite savanna habitats. Farther west, it lives in barren ground at the base of low clumps of mesquite (Schmidly 2004:425). In the pre-inundation ecological survey at Coleto Creek Reservoir, the few cotton rats trapped came from brushy pasture habitat (Table 10.28). Its contemporary range includes the southeastern U. S., the southern Plains, and most of Mexico and Central America. The genus *Sigmodon* is subtropical in origin, and the species (currently bounded on the north at about latitude N40°), now expanding northward, must adapt to colder winter temperatures (Scheck 1982). It appears occasionally in the Late Pleistocene-early Holocene record of Texas (for example, Friesenhahn Cave, Cave Without a Name, Longhorn Cavern, Levi Rockshelter, Lubbock Lake, Baker Cave, Schulze Cave, Richard Beene). At Wilson-Leonard, it is absent from the earliest deposits, making its first appearance in Level 41 near the top of Stratum 1 and becoming more frequent in the Holocene deposits above (Balinsky 1998:Table 35-2). *Sigmodon hispidus* has been characterized as limited by cold winter temperatures (Langley and Shure 1988), and it is curious that the species would become more common at Wilson-Leonard as increasingly severe winters encroached at the onset of the

Holocene. It is fairly abundant at Lubbock Lake (Johnson 1987:75), but absent from the Aubrey site.

Hispid cotton rats are often nocturnal but are also frequently active during the day, and as a result are preyed upon by Swainson's hawks, red-tailed hawks, and other hawks, as well as barn owls, short-eared owls, coyotes, and snakes. Like voles, they are prolific breeders prone to major cyclical fluctuations in population density, with crashes due to drought, freezes, or other factors. Population booms result from several successive rainy years with mild winters. It is interesting that, for a species with such potential for dense populations, only one individual is known from the bench deposits, and none from the hearth deposit. *Sigmodon hispidus* differs from most of the other rodents in the fauna in being a frequently diurnal herbivore, where most of the others are nocturnal granivores, but how this might result in its archeological scarcity here is unclear. Elsewhere, as at Hinds Cave and Baker Cave, it has been found in coprolites.

Arizona cotton rats (*Sigmodon arizonae*) were probably second only to woodrats as major food items among native American Indian populations of Arizona and Sonora, especially the Pima (Rea 1998:176-180). They were hunted with fire drives, rodent hooks, and clubs.

Microtus ochrogaster (Prairie vole, Fig. 10.76) and/or *Pitymys pinetorum* (Pine vole; Figs. 10.75, 10.77)

Element	Ambient bone NISP	Hearth deposit NISP
mandible		1
M^2		1
M^3	1 (N109 E103, 93.14-92.90 m)	
cheek tooth	1 (N109 E96, 92.35-92.30 m)	
molar, unspecified		1
M_1		1
M_2		1
proximal femur	1 (N109 E96, 92.50-92.45 m)	
metatarsal	1 (N109 E96, 92.50-92.45 m)	

Voles are especially interesting because they are perhaps the only climatically sensitive mammal in the bench deposits, and their geographic distribution appears to have changed frequently throughout the Quaternary, perhaps mostly in response to prevailing rainfall and/or temperature, and is still changing today. Their distinctive rootless, prismatic teeth are the elements usually recognized and studied. There are two species of voles remaining in Texas (several others suffered extinction earlier in the Pleistocene): the Prairie vole (*Microtus ochrogaster*) and the Pine vole (*Pitymys pinetorum*, sometimes listed as *Microtus pinetorum*). Figure 10.74 shows the continental distribution, although the part of this map that covers Texas does not include the most recent information. See Schmidly (2004:446) for the most up-to-date distribution map for Texas. The Prairie vole is a grassland species, covering much of the central U. S. and extending into Canada. The Pine vole is a woodland species of the eastern and southeastern U. S., and their ranges overlap in the upper Midwest and Mississippi drainage.

In Texas, a single small population of *Microtus ochrogaster ludovicianus* near Sour Lake (Fig. 10.74) was extirpated after 1902. Another subspecies, *Microtus ochrogaster taylori*, expanded into the panhandles of Texas and Oklahoma in the 1980s

Stangl, Goetze and Spradling 2004), perhaps in response to the alfalfa fields sustained by pivot irrigation systems there. This species, then, currently lives no closer to Berger Bluff than the Wichita Falls region. The Pine vole (*Pitymys pinetorum*), on the other hand, has a very patchy distribution across the entire northeastern quadrant of Texas with records in only 19 counties (Schmidly 2004:446). The closest populations to Berger Bluff are in the counties of Kerr, Gillespie, and Madison. No voles were recovered in pre-inundation trapping studies at Coleto Creek Reservoir.

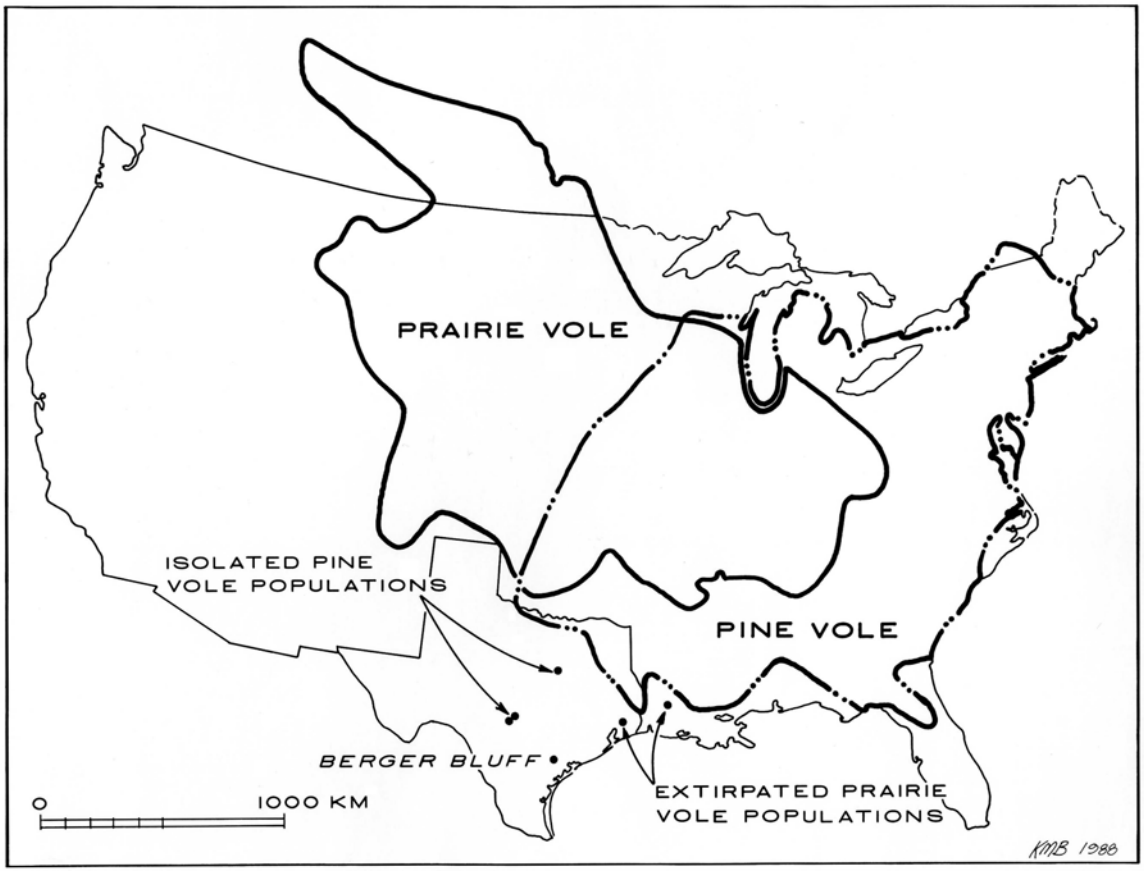

Figure 10.74. Range Limits for Prairie and Pine Voles. Additional populations of both species have been recorded in Texas since this map was drawn. See Schmidly (2004:446) for recent mapping.

Despite this very sketchy modern distribution, paleontological and archeological deposits show that voles were widespread in Texas in the Late Pleistocene, early Holocene, and Late Holocene (including the Late Prehistoric). The situation in the Middle Holocene is less clear – the distribution may have resembled today's, with voles largely absent (Graham 1987:Table 10, 11) during the Hypsithermal. The situation at Berger Bluff is a microcosm of that elsewhere in the state: microtine remains are present in the Late Pleistocene and earliest Holocene bench deposits and in the upper deposits atop the bluff, at the 15-30 cm and 30-45 cm excavation levels, but nothing is known about the distribution in the intervening Middle Holocene deposits, which have never been tested. Incidentally, Hulbert identified these as *Pitymys pinetorum*, but the specimens in question are an edentulous mandible and anterior half of a skull, whose specific identification ought to be rechecked. Microtines are also present in late context at 41 GD 21A (Fox, Black and James 1979:Table 3) and the Smith Creek Bridge site (Froelich 2002:Table 95). A plausible reconstruction of Quaternary range modulation for both vole species might look something like this:

Late Pleistocene-early Holocene:	Range expansion
Hypsithermal:	Range contraction
Earliest Late Holocene:	Range expansion
Medieval Warm Period:	Range contraction
Little Ice Age:	Range expansion
Historic:	Range contraction

Voles are small mice, related to the lemmings of Europe and North America. They are, generally, boreal-adapted mammals, and the fact that the ranges of both species have been displaced northward since the Pleistocene may indicate that summer maximum temperatures also act as a limiting effect. At present, the southern limit of the Pine vole is at about latitude N30° (mean daily maximum for August, 35° C or 95° F), while for the Prairie vole it is about N36° 30" (mean daily maximum for July, 33.9° C or 93° F). Dice

(1922:46) long ago suggested that Prairie voles could not tolerate summer maximum temperatures above 36° C (96.8° F), based on laboratory experiments. Suitable habitat for either species (prairie for the Prairie vole, postoak woodland for the pine vole) must have been present near Berger Bluff in the Late Holocene, and seems to be present still, so non-habitat factors must account for their contemporary absence.

According to Semken and Wallace (2002:24; also compare Fig. 4, h and i), the only element useful for discriminating between these two species is the lower first molar. Only one of these was recovered, a left lower first molar from the hearth deposit (Unit 2, Feature 5 and adjacent surface, lot B-149; Fig. 10.76), but fortunately it is in good shape, with a readable occlusal surface. According to Semken and Wallace, *Microtus ochrogaster* lower first molars have the following features:

1) a broad (>0.2 mm) "isthmus" between the 6^{th} and 7^{th} re-entrant angles;
2) only the medial portion of each re-entrant is oriented anteriorly;
3) enamel tends to be thicker on the leading edges relative to the trailing edges;
4) the 6^{th} re-entrant angle is shallow and tends to be directed at a right angle to the long axis of the tooth (Semken and Wallace 2002:29-30).

The lower first molar shown in Fig. 10.76 seems to meet all four criteria (this can best be seen by comparing the photo to Fig. 4, "h" and "i" of Semken and Wallace), and I conclude it is a good match for *Microtus ochrogaster*. If it is reasonable to assume all the microtine elements in the hearth deposit come from a single individual, then these may be Prairie vole as well. The remaining elements, from N109 E103 and N109 E96, probably

represent at least three more voles, based on stratigraphic separation, but there are no teeth suitable for speciation.

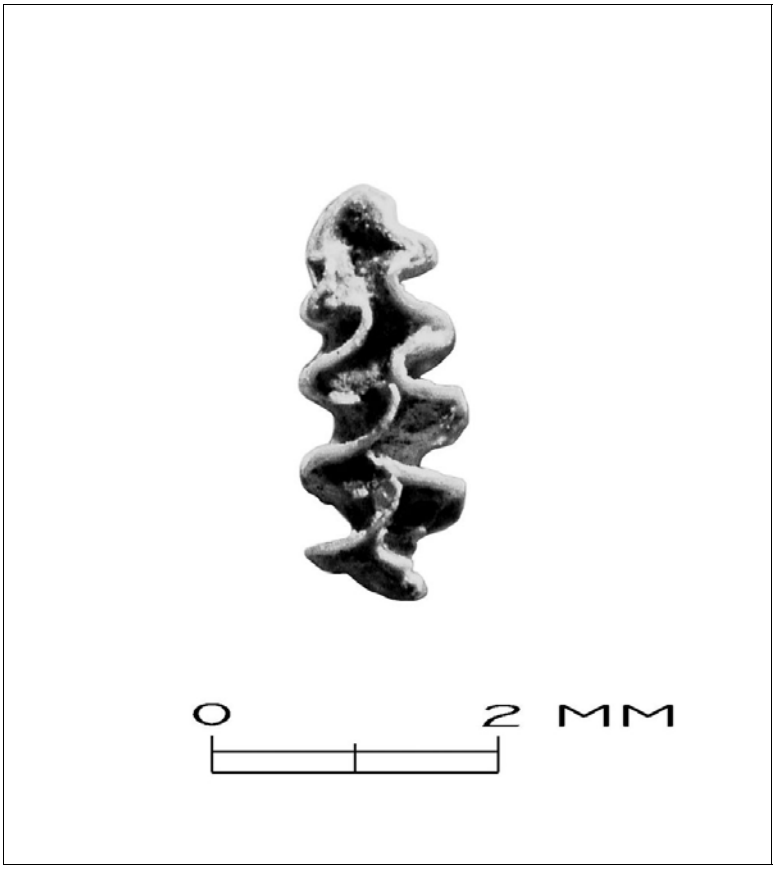

Figure 10.75. Microtine Molar From Ambient Bone. Occlusal surface of lower first molar of Microtus/Pitymys sp., from coarse fraction of wet-sieved bulk matrix passing the ¼-inch screen. N109 E96 (92.55-92.50 m), no lot number assigned yet. Note degraded edges of occlusal surface.

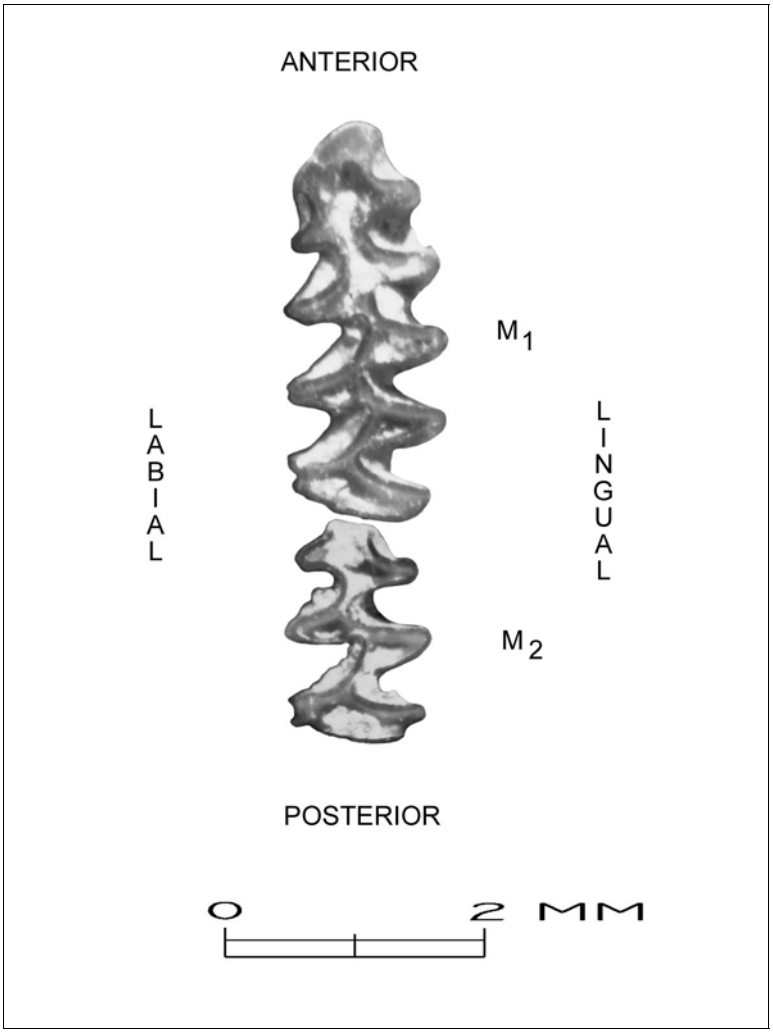

Figure 10.76. Closeup of Microtine Teeth From the Hearth Deposit. Occlusal view of loose lower left first and second molars (*Microtus ochrogaster*) arranged in approximate anatomical relationship. From Unit 2, on surface of Feature 5 and immediately surrounding area, at 92.38 m; lot B-149.

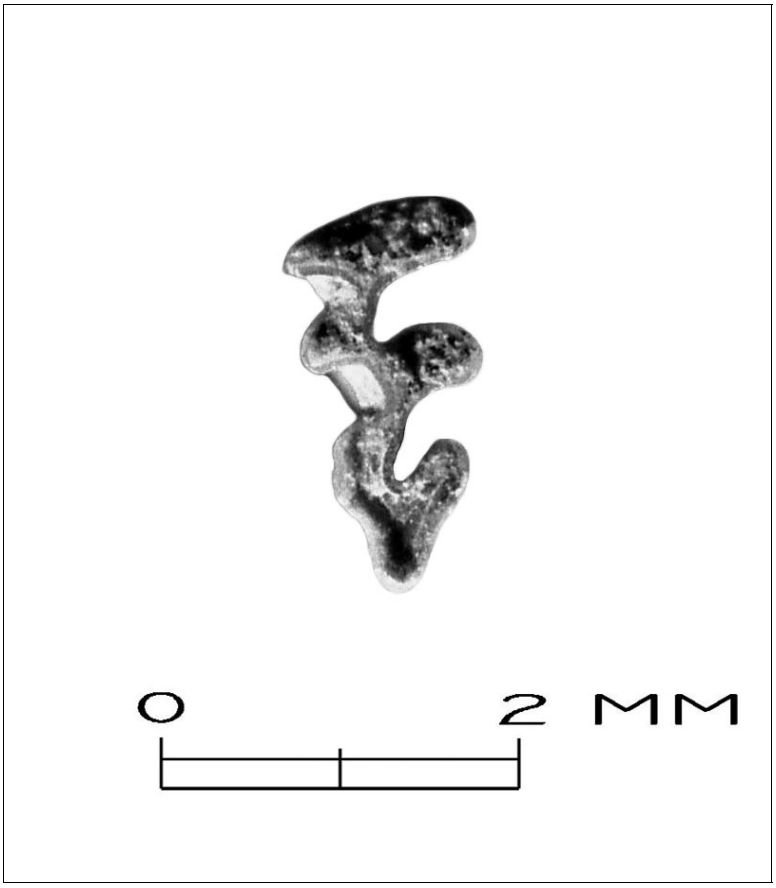

Figure 10.77. Microtine Molar From the Hearth Deposit. Occlusal surface of *Microtus* sp. upper right third molar. N113 E98 (approximately upper 5 cm of 92.40-92.30 m level), lot B-107A, coarse fraction of loose matrix wet-sieved by Cabaniss. This specimen comes from an unstudied lot and is not listed in the specimen table at the head of this section. It compares fairly well to *Microtus ochrogaste*r.

Figures 10.78 and 10.79 illustrate additional microtine specimens from excavation levels 2 and 3 in the excavation block in the upper deposits. The anterior skull segment shown in Figure 10.78 is probably derived from an owl pellet, because removal of the occipital area is characteristic of owl predation.

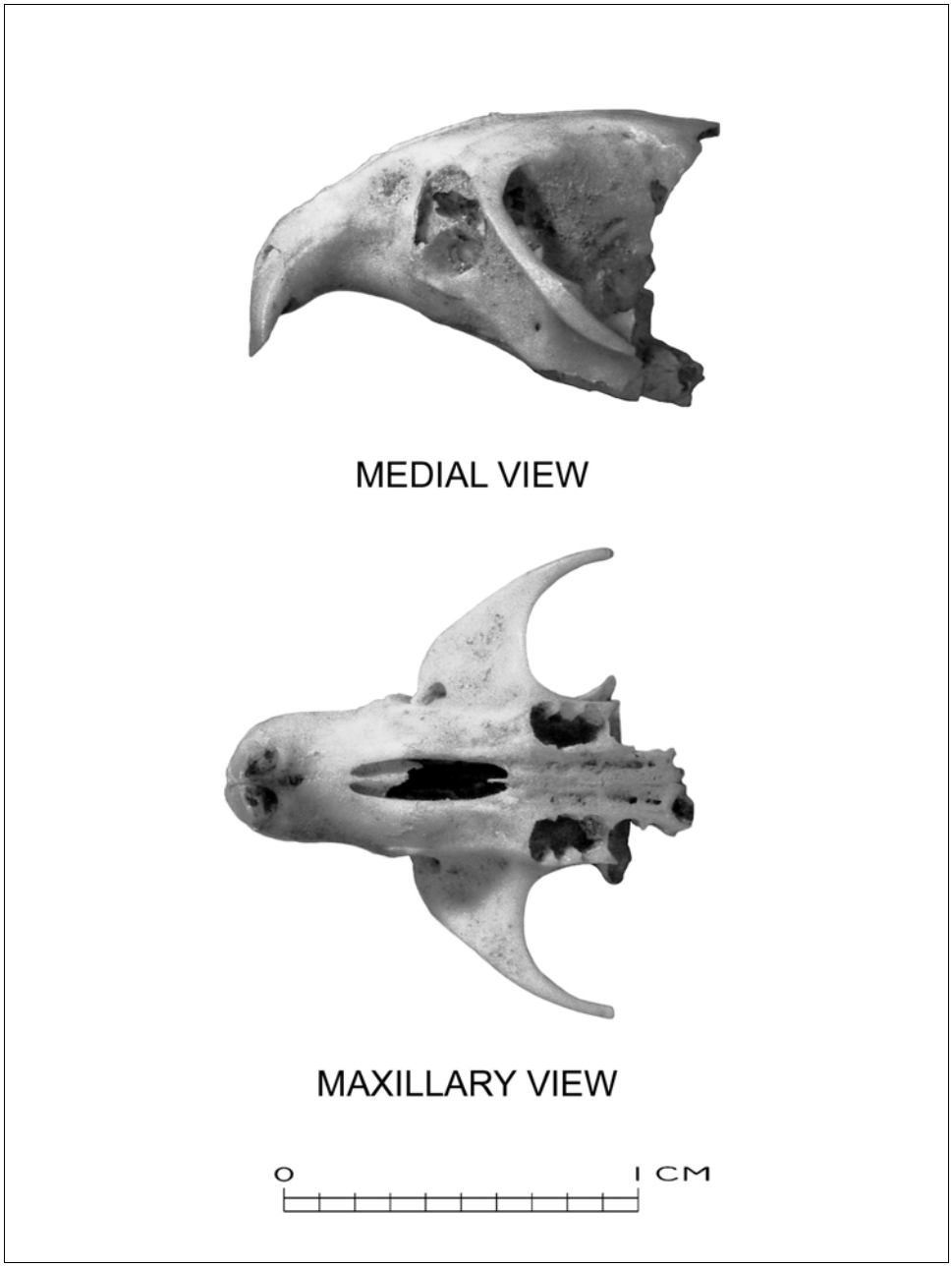

Figure 10.78. Microtine Skull From the Upper Deposits. Medial and maxillary views of *Microtus/Pitymys* sp. skull from the upper deposits at Berger Bluff, N98 E97 (level 3), lot 1.

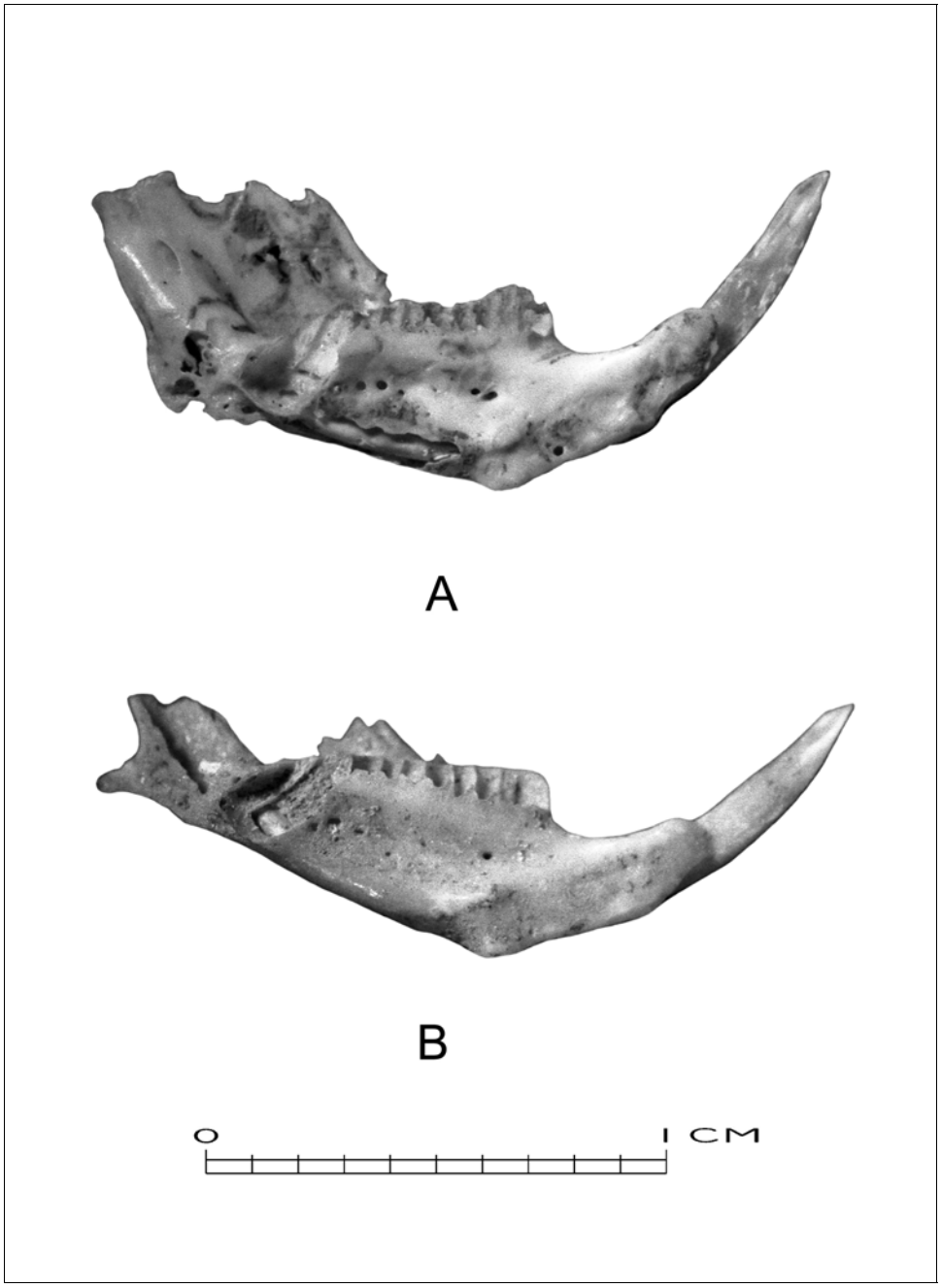

Figure 10.79. Microtine Mandibles From the Upper Deposits. A, left mandible of *Microtus/Pitymys* sp. (lingual view) from stratum 5, N97 E99 (level 2, 99.80-99.65 m); B, left mandible of *Microtus/Pitymys* sp. (lingual view) from stratum 5, N98 E97 (level 3, 99.65-99.50 m?), lot no. 2.

Both of these voles are small to medium-sized stocky mice with short legs and relatively short tails. Prairie voles have a body length of about 10-13 cm and weigh about 30-50 g (average about 38 g), Pine voles about 25-45 g. Prairie voles live in:

1) drier upland prairies
2) weedy fields and thickets, including disturbed or disclimax vegetation
3) riparian habitat only if grassy and unforested
4) rarely in upland forest

Grasses such as bluegrass or brome, and thickets of dewberry or broomsedge are prime habitat, and the postoak parkland on the Beaumont and Lissie terrace surfaces would probably be good Prairie vole habitat. Pine voles live in:

1) deciduous forest with heavy leaf litter
2) grassy or weedy areas, including disturbed or disclimax vegetation
3) swampy areas with sedges
4) edge areas between woodland and meadow

Both species are fossorial, especially the Pine vole, which digs complex tunnel systems (2-5 cm diameter, 10-30 cm deep) just below the litter layer. Prairie voles have similar systems (Mankin and Getz 1994:Fig. 1), but surface runways are more extensive. Entrances are marked by dirt piles and grass clippings. Tunnels are about 4.7 cm in diameter and 14 cm deep, but nest chambers are about 5-6 cm deep (Mankin and Getz 1994:Table 1). Prairie voles prefer to burrow in sand. Both species live in groups. They do not hibernate and are active both day and night (although Prairie voles have been

reported in the literature as nocturnal, diurnal, and crepuscular). Prairie voles in lab colonies will submit to frequent handling by humans.

Like cotton rats, both species are subject to population cycling, so population density statistics vary widely. For Prairie voles, densities of less than one to 360 per hectare have been reported (up to a remarkable 1060/hectare in one study). For Pine voles, densities of less than one to 222/hectare have been reported. Both species are herbivorous for the most part (grasses, sedges, forbs, roots, tuber, fruits, seeds, etc.).

It may come as a surprise to many archeologists, but voles of one species or another have been recovered widely from Texas archeological sites, mostly Holocene. They have been recovered archeologically from the following counties: Bexar, Bosque, Briscoe, Collin, Cooke, Coryell, Dallas, Delta, Denton, Fort Bend, Freestone, Goliad, Hill, Hopkins, Jackson, Jim Wells, Live Oak, Lubbock, Montague, Navarro, Randall, San Patricio, Swisher, Travis, Uvalde, Val Verde, Willacy, Williamson, Wood and probably others I have overlooked.

The nature of this interaction between humans and voles is seldom clear, but skull fragments, teeth, and possibly other elements of *Microtus* sp. were recovered from a human coprolite at Salts Cave, Kentucky (Watson 1969:55). Occasionally, provocative numbers of microtine remains are recovered from archeological sites in contexts that strongly suggest human exploitation. One example is the Schmidt site in Nebraska, where 20% (= 6 of 31?) of the *Microtus* mandibles from Feature 221 were charred, suggesting cooking (Satorius-Fox 1982:60). Another example is the Stigenwalt site in Kansas, an Early Archaic site (7410 ± 70 RCYBP, Tx-5694; 7590 ± 100 RCYBP, Tx-6050) with

burned limestone features resembling central Texas incipient burned rock middens, in which remains of *Microtus ochrogaster* or *Pitymys pinetorum* were found (NISP = 155, MNI = 4), and 24 out of 155 elements showed evidence of burning (Thies 1990:Table 1, 3). A third example is the Medicine Lodge Creek site in Wyoming, where six different species of voles were found (Rodent Level Faunule, MNI = 323; Deep Deer Faunule, MNI = 4; Fire Pit Faunule, MNI = 4; Pryor Stemmed Faunule, MNI =2; Walker 1975:Table 1, 2, 5, 6). The minimum number of 180 *Microtus ochrogaster* individuals in the Rodent Level Faunule (9590 ± 180 RCYBP, RL-393) is particularly notable. This faunule is about the same age as the stratum 2D deposits at Berger Bluff. Walker concludes

> Basically, the remains indicate an attempt toward complete utilization of all possible food resources for life existence. No animal group was ignored in the quest for food by the prehistoric inhabitants of the area. Snakes, lizards, birds, rabbits, rodents, carnivores, cervids, and bovids were all collected and utilized as food.
>
> A minimum number of 101 pocket gophers, 135 bushy-tailed wood rats, 134 montane voles and 180 prairie voles are represented in this midden… (Walker 1975:8).

Another possible example might be the Spring Creek site in Nebraska (Grange 1980).

Neotoma cf. *N. micropus* or *N. floridana* (cf. Southern Plains or Eastern woodrat; Fig. 10.38, D; 10.42, D-F; 10.45, E-G; see also Fig. 10. 39, D; 10.46, D, E for unidentified woodrat-sized rodent remains)

Element	Ambient bone NISP	Hearth deposit NISP
M^1		1
M^2		1
M^3		1
incisor		1
molar, unspecified	1	
M_1		1
M_2		1
scapula		1
ischium		1
humerus		2
femur		1 (young adult)
caudal vertebra		3
fragments, mandible?		23*

* Probably fragments of disintegrated mandible represented by lower molars and incisor. Also note Lot B-4 has a tooth enamel fragment, possibly from a *Neotoma* molar.

Two species of woodrats (or packrats, as they are sometimes called) with essentially parapatric ranges meet in a boundary near the Guadalupe River (Dalbey 1980). The Southern Plains woodrat, *Neotoma micropus*, is a typical south Texas resident of the chaparral in Tamaulipan biotic province, while the Eastern woodrat, *Neotoma floridana*, is an East Texas woodland dweller. Curiously, no woodrats were recorded in the reservoir area by the pre-inundation ecological survey (Table 10.2), but *Neotoma micropus* is recorded from the counties of Goliad, De Witt, Karnes, Refugio, and Calhoun (Dalbey 1980:Fig. 5; Schmidly 2004:437), as well as the Guadalupe Delta Wildlife Management Area.

Southern Plains, Eastern, and White-throated woodrats are all so closely related phylogenetically that even rodent specialists sometimes have trouble distinguishing them using diagnostic features like coat color. They also readily interbreed and hybridize

where their ranges abut (Birney 1976; Zimmerman and Nejtek 1977). Discriminant analysis can separate the two species, and shows that Eastern woodrats are slightly larger (Dalbey 1980:58). Southern Plains woodrats weigh about 204-310 g (average about 240 g), while Eastern woodrats weigh about 200-350 g (average about 265 g). Figure 10.80 illustrates first and second molars for comparative specimens of both species and shows how similar the teeth are.

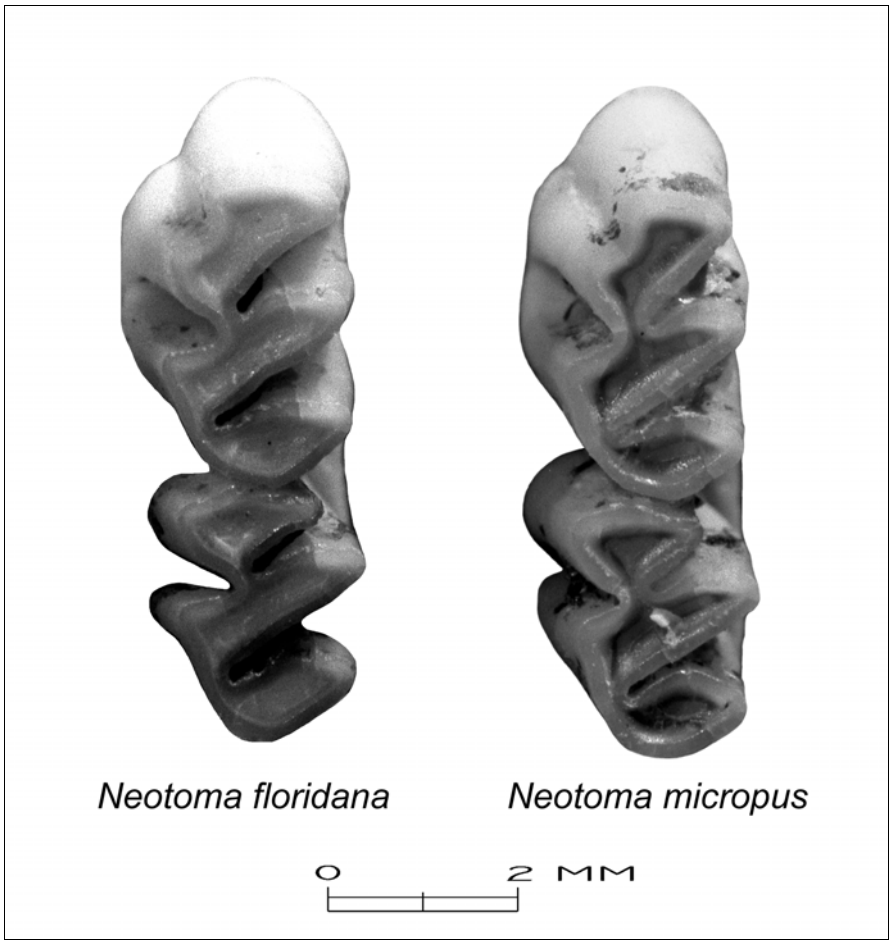

Figure 10.80. Comparative Specimens of *Neotoma* Molars. Recent specimens of the upper left first and second molars of *Neotoma floridana* and *Neotoma micropus* from the UTSA-CAR comparative collection. These differ little in appearance except for the degree of tooth wear

Schmidly (1983:202, Fig. 4) maintains that Southern Plains woodrats can be distinguished from Eastern woodrats by virtue of a much less well-developed anterointernal reentrant angle on the upper first molar. A single left upper first molar is present in the hearth deposit (N113 E98, 92.443-92.400 m, lot B-106) for comparison with a reference specimen of *N. micropus* and Schmidly's Figure 4. The specimen is from an adult with lightly worn teeth and the anterointernal reentrant angle is very poorly developed (Fig. 10.81). By this criterion, it compares very well with *Neotoma micropus*. A second test depends on the width of the second loph of the lower first molar (see Lundelius 1979:250, Harris 1984). A single lower first molar is present in the hearth deposit (N113 E98, 92.50-92.40 m, lot B-105, Fig. 10.82). The width of the second loph was measured with a microscope reticle at 1.86 mm, narrower than the mean (1.998 mm) for *Neotoma micropus* comparative specimens measured by Harris, and in fact beyond one standard deviation, but within the range (1.84-2.21 mm) given. Harris found *N. floridana* measured 1.93 mm or greater. By this criterion, then, the Berger Bluff teeth seem to pertain to Southern Plains rather than Eastern woodrats (however, see Graham 1976:80-82, Fig. 15, for cautionary discussion). As in the case of *Microtus* teeth, large samples are really needed for reliable species discrimination.

Southern Plains woodrats and Eastern woodrats have fairly distinct habitat preferences, with the former occupying mostly chaparral or arid brushland terrain and the latter, mesic woodlands and rocky outcrops. The most relevant data on habitat preference of both species are from a study by Dalbey (1980) in De Witt, Gonzales, Guadalupe, and Wilson counties. Dalbey found that most *Neotoma micropus* were found in thornbrush-prickly pear associations; 70% of the individuals trapped came from prickly pear patches, 14% from woodpiles, 9% from abandoned buildings, and

7% from open areas (Dalbey 1980:25). Thornbrush consisted most often of mesquite and *Condalia*.

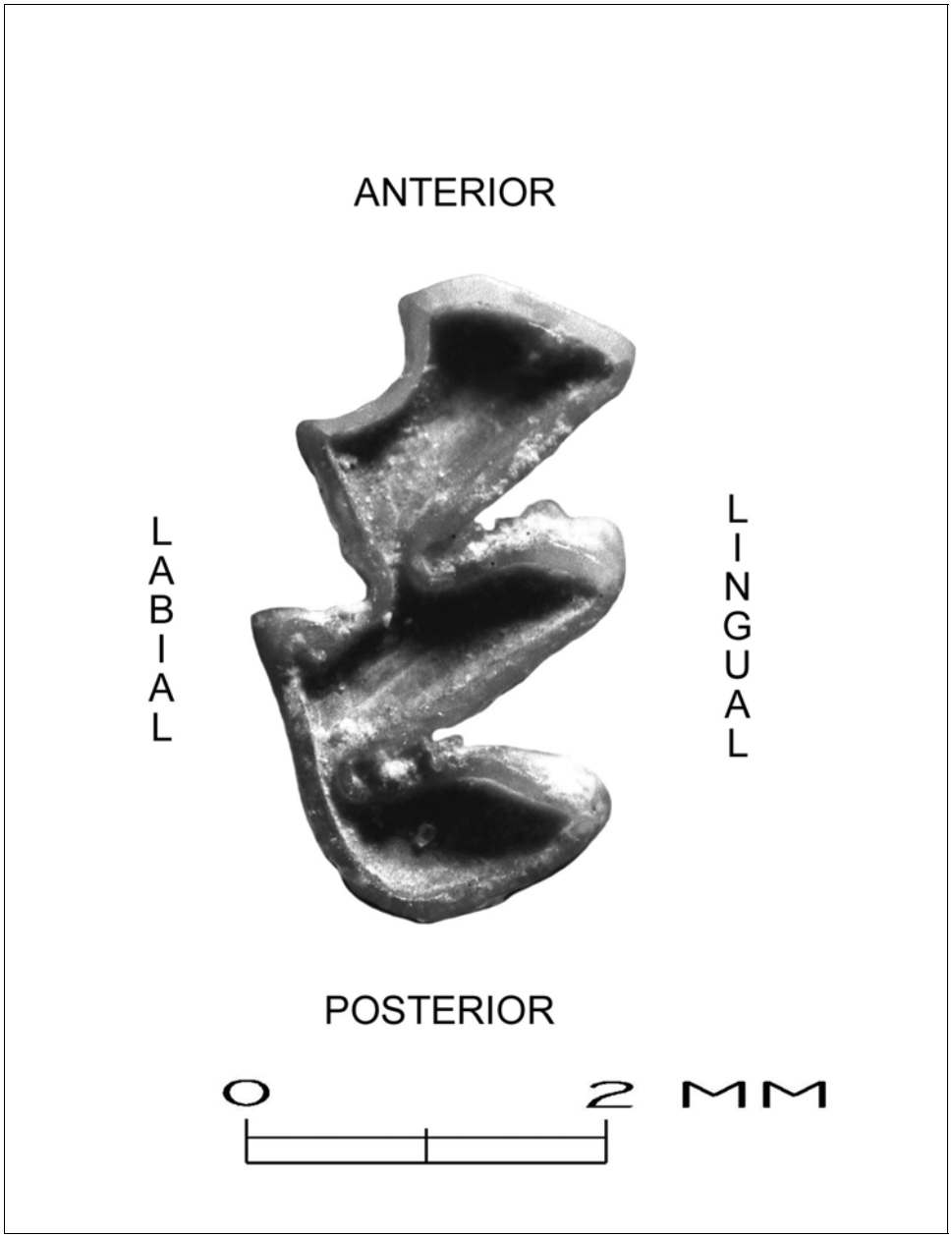

Figure 10.81. Closeup of *Neotoma* Molar From the Hearth Deposit. Occlusal surface, upper left first molar of *Neotoma* sp. from N113 E98 (92.443-92.400 m), lot B-106. The second and third molars are also present in this lot, but not shown here.

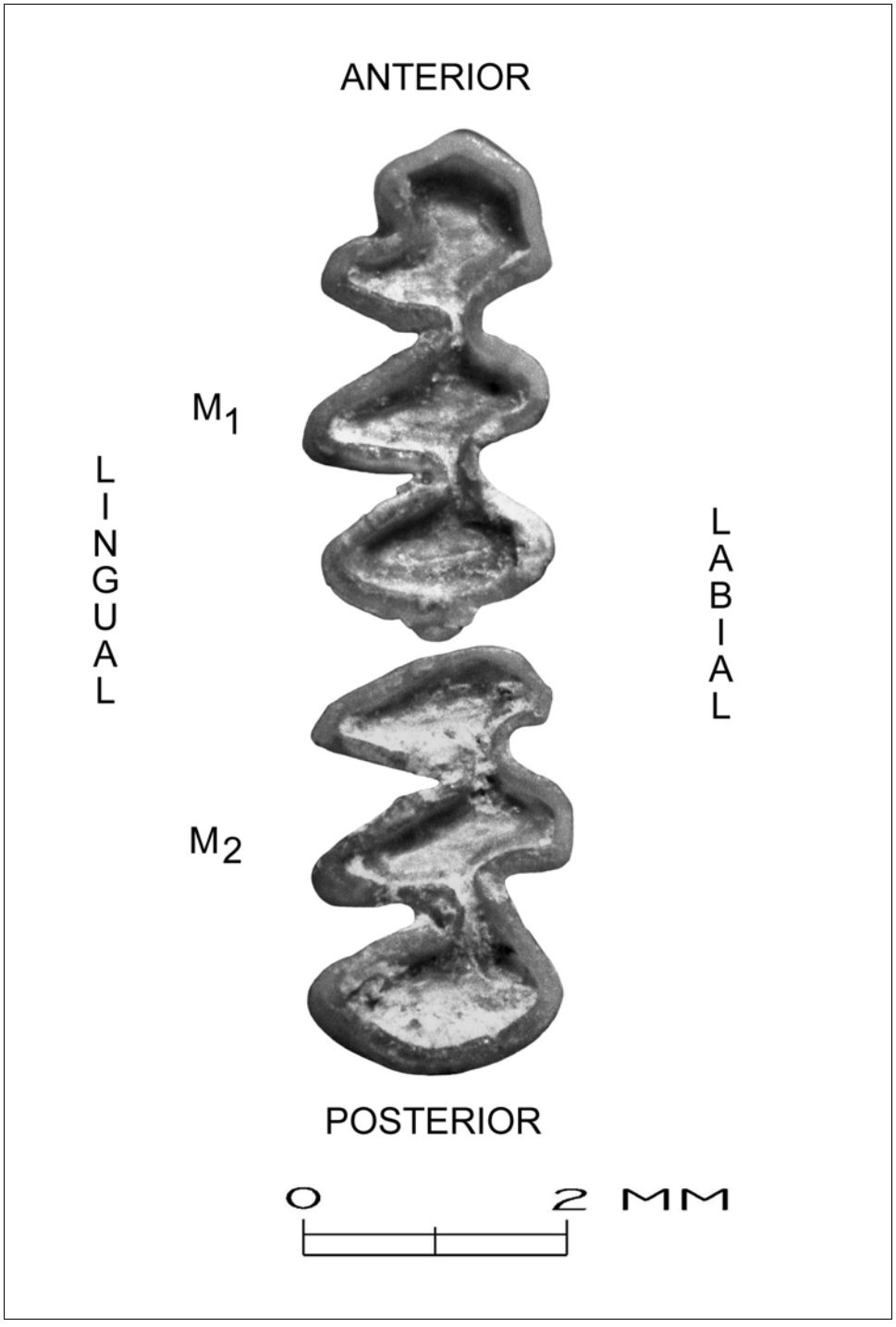

Figure 10.82. Closeup of *Neotoma* Teeth From the Hearth Deposit. Occlusal view of *Neotoma* sp. lower right first and second molars from N113 E98 (92.50-92.40 m), lot B-105.

Raun (1966) studied the species in a prickly pear-shortgrass community (with mesquite and granjeno) at Welder Refuge, near Sinton, and found the rats closely associated with prickly pear patches. Box (1959) also studied Southern Plains woodrats at Welder Refuge and likewise found them most common in the prickly pear-shortgrass community and absent in the bunchgrass-annual forb community. Likewise, in Zavala County, Johnson (1952:13-32) found them most common in the mesquite-cactus community (30 dens per acre, 74 per hectare), less so in the mesquite-brush community (10 dens per acre, 25 per hectare), and nearly absent in other habitats; 70-80% of dens in the mesquite-cactus community were directly associated with prickly pear. Other studies elsewhere in Texas and New Mexico have found them in mesquite savanna, ravine, cedar bluff, or sandy habitats. The close association in south Texas of *Neotoma micropus* with *Opuntia* (both prickly pear and tasajillo) is significant, since neither of these plants occurs very commonly nor in extensive patches in the Coleto Creek Reservoir area at present. Both *Opuntia lindheimeri* and *Opuntia leptocaulis* are present, but are insignificant in comparison to most other areas of south Texas. *Opuntia leptocaulis*, for example, accounts for only 0.02% of cover in the live oak stand habitat (Espey, Huston and Associates 1976:Table 2-13). It is also noteworthy that no woodrats of either species were trapped during the Espey Huston study.

In the study by Dalbey (1980:26-27), 70 % of his Eastern woodrats were trapped in prickly pear patches (in blackland prairie, mixed woodland, and mesquite grassland), while 25 % occurred in wood piles and one individual was found in an abandoned house. Over much of the rest of Texas, post oak woodland is more typical habitat for Eastern woodrats (Schmidly 1983:197; Dalquest and Horner 1984:150; Raun 1959:Table 1; McCarley 1959:411); in East Texas, the species may occur in hardwood or pine

forested bottom lands (Baker 1942), although Lowery (1974:256) says it is rare or absent in dry upland pine forest in Louisiana. In Oklahoma, the species also prefers ravines in areas wooded with post oak and blackjack oak (Murphy 1952:206; Hays 1958:242; McCarley 1952:108). Goertz (1970:97-98) found the species most common in upland woods, including dry ravines, less so in brushy riparian woods; edge areas had fewer woodrats. In north central Oklahoma, Schnell *et al*. (1980:Table 1) found Eastern woodrats most common in lowland forest with coralberry, elm, and other woody vegetation. In many parts of the eastern United States, the species may be found in swamps or marshes, and in grasslands it is mostly confined to gallery woods. Where rocky bluffs or ledges are present, their distribution may partly govern the occurrence of the species (Cudmore 1985). The above information shows clearly that the most likely modern habitat for Eastern woodrats near Berger Bluff would consist of wooded ravines and those parts of the post oak woodland with more closed canopy on the Lissie terrace surface, even though woodrats are not known to live there now.

Population densities estimated for Southern Plains woodrats are 0-31 per hectare at Welder Refuge (Raun 1966:37), 50 per hectare in Zavala County (Johnson 1952:79. For Eastern woodrats, reported densities include 25 per hectare in Brazos County (Tate 1970:10), about 2 per hectare in Polk and Tyler counties (Baker 1942), and 0.62-7.19 per hectare in Oklahoma (Schnell *et al*. 1980:Table 1).

Southern Plains woodrats are almost wholly vegetarian, subsisting chiefly on foods such as prickly pear pads and tunas; Raun observed that in the summer, south Texas woodrats have red-stained muzzles from eating ripe tunas (Raun 1966:8). Tasajillo stems are used in house-building where prickly pear is not available, and

possibly the tasajillo tunas are eaten as well. Other favored foods include mesquite bean pods, acorns, wild plums, Ephedra needles (Dalquest and Horner 1984:154), agarita and granjeno berries (Box 1959:715). Other kinds of bark, roots, nuts, or seeds may be eaten. Like the heteromyid rodents, Southern Plains woodrats are said to obtain their water intake from food, although they will drink free water if necessary (Davis 1966:201; Bailey 1971:174; see also Olsen 1976).

Eastern woodrats have a diet that reflects their typically more forested habitat. Favored items are acorns, nuts, or leaves of post oak, water oak, walnut, pecan, hackberry; fruit and leaves of yaupon, cactus stems and tunas, mushrooms, wild grapes, juniper berries, leaves of pecan, French mulberry, greenbriar, perppervine, trumpet vine, rattan, sumac bark and seeds, and many other kinds of vegetation; snails and insects are also said to be eaten on occasion (Schmidly 1983:200; Dalquest and Horner 1984:151; Lay and Baker 1938). Eastern woodrats can also subsist without drinking water, and their dens are often located far from water sources (Murphy 1952:211).

Woodrats are nocturnal animals. Raun reports Southern Plains woodrats at Welder Refuge were most active between dusk and midnight, with 82% of the animals trapped before 9 PM; weather conditions or moonlight did not appear to affect capture rates (Raun 1966:18-19).

Woodrats of all kinds are well known for building houses or dens from various expediently collected materials. Species living in rocky areas often build them under ledges or overhangs, but woodrats living elsewhere build their dens in the open, often against or among standing vegetation, especially cactus (see Bailey 1971:171-172;

Birney 1973:29). Johnson (1952; see Raun 1966:Appendix III) gives a detailed description of *Neotoma micropus* dens in Zavala County, where typical dens are conical, 20-24 inches (51-61 cm) high and about 36 inches (91 cm) in diameter. Dens may be built around prickly pear patches, at the base of mesquite trees, or over fallen logs and are evidently constructed at night of sticks, animal dung, and other materials, and in south Texas are frequently armored with cut pieces of prickly pear or tasajillo. Hester and Hill (1980) describe two houses in Zavala County, built of typical chaparral vegetation (prickly pear, mesquite, lotebush, huisache, tasajillo, granjeno, and guayacan) and slightly larger in diameter than the average size reported by Johnson. Raun (1966:20) found that in areas of Welder Refuge where building material was scarce, dens were insubstantial low mounds of debris in cactus patches, and the lack of above ground structure was compensated by fairly extensive burrow systems. Johnson found three entrances (usually about 2 inches above ground level) to be typical, although as many as five were seen; inside a central chamber about eight inches (20 cm) in diameter is usually found, with three side chambers, one of which contains the nest; food storage chambers containing seeds or other food items may be found (Raun 1966:57). Johnson found that some dens had burrows leading underground from the center of the den, about 20 cm under the surface. Finley (1958:490-491) found 2-3 nests per den, all underground, and also reports "escape tunnels;" one of these was U-shaped, running 2.5 feet (75 cm) away from the den to a depth of 14 inches (36 cm), then doubling back to emerge near the den. Some dens have mazes of sunken or underground passageways, as well as networks of surface runways leading away from the den (Dalbey 1980:25). Woodrat dens have a distinct musky odor, and scent marking has been reported for western species of *Neotoma*. In south Texas, cotton rats and white-footed mice (*Peromyscus leucopus*) may co-occur in *Neotoma micropus* dens.

Woodrats were probably hunted by every native American group in whose territory they occurred. Next to rabbits, they are the most common small animal food source mentioned in ethnographies, especially for the Southwest, California, Mexico, and the Great Basin. Hunting was done by tearing down occupied dens with sticks or rodent hooks, or setting the den on fire, killing the evicted rats with sticks or bows and arrows, or by trapping with deadfalls. John Rope, a Western Apache informant interviewed by Grenville Goodwin, recalled,

> We boys used to hunt pack rats with bow and arrows. A lot of us used to start out in the morning and hunt till mid-afternoon. The way we got the rats was by one boy poking a long stick into the rat's nest. The other boy would stand near the nest entrance on the opposite side. When the stick was poked in, the rat would come to the door and stick his head out. Then the boy would shoot him. Sometimes the rats would come to the door and then go back. If they would not come out, we would tear the house down and dig them out of their hole. We would poke our stick in the hole and if there was hair on the end of it when we took it out, then we knew the rat was there and we would dig him out (Basso 1971:97).

A Chiricahua Apache informant quoted by Opler reported that

> The Chiricahua hunt those big rats and eat them. Two men go to a nest. One pokes a stick in; the other waits at the other end and shoots when the rat comes out. For this they use a small arrow the same as is used for birds. It is all wood, with a sharpened point. When they get a good many rats, they pierce the legs and carry them home on poles over the shoulder. Sometimes to get them a person pokes into a hole and hits them with a stick when they come out (Opler 1965:325).

Gifford (1936:266, 275) gives the following account of how woodrats were used by the Yavapai:

> Woodrats caught in stone deadfall trap, without bait, so placed that animal sprang trigger in passing. Trap at times baited with cooked mescal. Set by man.
>
> Woodrat nests in cacti or bushes pulled to pieces with 6- to 8-ft. stick with curved end; stored pinon nuts taken, rats killed as they left nest. Shot with arrows, hit with sticks, or seized by necks in bare hands and struck against rocks. Rats poked out of nest with straight end of stick; if they did not come out, crooked end of stick used to pull nest to pieces. Rats tied in pairs with soaproot fiber around necks. Eight pairs might be tied on one piece of fiber. Woodrats boiled whole (NE Yavapai), with intestines removed (W Yavapai). Some baked under ashes. Skinned before baking and skin placed in cleaned abdominal cavity. Skin eaten as delicacy. Woodrats skinned, slightly charred, and hung in hut in bundles of 20 or 30, kept for a few days. Boiled later. Woodrat brains sometimes preserved for skin dressing.

Referring to *Neotoma micropus* in Aransas County, J. A. Allen (1894:175) wrote "Capt. N. C. Phillips, an old settler, says these rats are excellent eating, in his estimation far superior to squirrel meat." Remains of woodrats commonly occur in Texas archeological sites, in shelters, caves, and open sites alike. They occur in the upper deposits at Berger Bluff, in levels 2 and 3 (Flynn 1983). *Neotoma* remains have been found in human coprolites at Caldwell Cave (Holloway 1985:Table 4), Granado Cave (Hunter 2001:Table 13.4), Hinds Cave (where remains, including at least two juveniles, occurred in 19 or 20 of the coprolites studied; Williams-Dean 1978:Table 10) and Baker Cave (Sobolik 1988:Table 15).

cf. *Lepus californicus* (cf. Black-tailed jackrabbit)
Ambient fauna (N109 E96, 92.50-92.45 m, bulk matrix sample, lot B-157)
1 scapula fragment

A calcined fragment of the border of the glenoid fossa from a right scapula has been identified as Black-tailed jackrabbit. This is a large rabbit weighing about 1.5-4.0 kg. It is native to the western and southern parts of the state in sparsely vegetated areas,

but has spread to most of the rest of Texas as a result of artificial land clearance (Schmidly 1983:112). They are crepuscular herbivores. Recorded from the reservoir area during the pre-inundation survey, they presumably would have been found in open upland prairie areas.

Sylvilagus cf. *S. auduboni* or *S. floridanus* (Desert or Eastern cottontail; Fig. 10.25)
Ambient fauna
1 mandible (N109 E103, 92.84-92.80 m, lot B-5)
1 astragalus (N109 E103, 92.84-92.80 m, lot B-5)
2 tibia fragments (calcined; N109 E96, 92.45-92.40 m, lot B-136)

Hearth deposit
1 M_3
1 calcaneum (young adult)

These items were identified as either Desert or Eastern cottontail. However, at present the xeric-adapted Desert cottontail occurs only in the west half of the state and is recorded no closer than Duval County. The Eastern cottontail (*Sylvilagus floridanus*) is distributed over most of the state and was recorded from the reservoir area in the pre-inundation ecological survey. It seems like a more likely identification for this rabbit material. Swamp rabbit (*Sylvilagus aquaticus*) also occurs in the area but is a larger rabbit.

The Eastern cottontail is medium-sized rabbit weighing about 1-2 kg. It occupies brushy and grassy areas and should be most likely found in postoak parkland on the Beaumont and Lissie terrace surfaces. They are crepuscular herbivores.

Sylvilagus sp. (unidentified cottontail rabbit; Fig. 10.29, E; 10.30, F; 10.38, C)

Element	Ambient bone NISP	Hearth deposit NISP
mandible	1	1
cheek tooth, unspecified	1	
scapula	1	
ilium	1	
vertebra	1	
distal femur	1	
proximal tibia	1	
distal tibia	1	
calcaneum	2	
astragalus	2	
metatarsal	1	

These elements cannot be speciated, but most come from a small species of rabbit. Possibly these represent more Eastern cottontail elements.

cf. Leporidae (cf. unidentified rabbit; Fig. 10.37, C)
Ambient fauna (N113 E98, 92.20-92.15 m)
1 distal metapodial

This is a distal metapodial fragment from a large rabbit (?), *perhaps Sylvilagus aquaticus* or *Lepus californicus* (?), but too badly fragmented for identification.

Rabbit or bird
Ambient fauna (lots B-5, B-7, B-9, B-11, B-34, B-50, B-73, B-76)

Present in the ambient fauna are 10 gracile long bone shaft fragments (or carbonate steinkerns) too fragmentary to distinguish between rabbit or bird. However, since no large birds are known from the bench deposits, I suspect these are all rabbit or some comparably-sized mammal.

Procyon lotor (Raccoon; Fig. 4.57, 10.16, 10.29, H)
Ambient fauna
1 M1 (N110 E102, 92.60-92.55 m, lot B-40) *?Procyon lotor*
1 distal humerus (Cutbank profile, stratum 2C, 92.46 m)

The only raccoon elements come from the ambient fauna: a lower first molar (in carbonate concretion) tentatively identified as raccoon, and a cutmarked left distal humerus (discussed earlier in this chapter). Lot B-123 also has the centrum from a caudal vertebra from some unidentified raccoon-sized animal. Adult raccoons from San Patricio County average about 6 kg (up to 11 kg for males; Gehrt and Fritzell 1999:Fig. 1).

SUMMARY AND CONCLUSIONS FOR CHAPTER 10

Animal bone from the bench deposits is generally in good shape, except for mechanical breakage. Breakage is due to predator mastication, matrix compression, or excavation damage. Fluvial abrasion appears to be essentially absent, and chemical rounding and dissolution are minimal. About 30 taxonomic categories can be recognized, and compared to other Texas sites of similar age, only Lubbock Lake, the Aubrey site and the Driscoll site have greater species richness. The bone fragments identified in this chapter represent only about half the bone recovered so far from the bench deposits. The other half remains unstudied, and additional bone is known to be present in matrix samples that have not yet been picked, so there is considerable potential for additional species to be added to the species list (Table 10.1).

The Berger Bluff fauna is essentially Holocene in character, for the most part. One extinct species is tentatively recognized: extinct giant tortoise, *Gopherus hexagonatus*, based on a very small carapace fragment less than 2 cm across.

The identification is tentative only because of the small size of the fragment; morphologically, it is a very good match for a comparative specimen from the Ingleside site, and I consider it a fairly confident identification. It is identical in appearance to the other bone from the site and shows no indication of having been reworked from older deposits. The specimen was recovered 50-55 cm below radiocarbon sample AA2831 (9880 ± 90 RCYBP, uncalibrated) and is older than that assay by some unknown number of years. It is likely to be one of the youngest examples of this species documented in North America, but the assay provides only a minimum age.

Animal bone in the bench deposits occurs in two different forms: 1) *ambient bone*, or a low-density background scatter of small bone fragments; 2) the *hearth deposit*, a concentrated microvertebrate bone bed discovered next to Feature 5, a small unprepared hearth buried in stratum 2B sediments (Tx 3569, 11,550 ± 800 RCYBP, uncalibrated). Based on incomplete preliminary counts, the ambient bone appears to have a stratigraphic preservation gradient similar to the snail shell, declining in frequency with greater depth. Since the bone (including the deeper samples) shows little microscopic evidence of chemical dissolution, the reason for declining frequency is not yet clear. It might be due to greater matrix expansion and compression at depth, to decelerating sedimentation rates, or to unrecognized chemical removal of bone.

The Berger Bluff vertebrate assemblage does not look like the kind of bestiary that archeologists are accustomed to seeing in most archeological sites. The animals here are mostly small, reclusive, and heavily weighted towards amphibians and rodents. I believe this is because at this early stage in its history, the site functioned mostly as a *diurnal way station* for parties of women, children and dogs foraging in the Coleto Creek

valley and adjacent uplands for plants and animals. Only much later in its history, in the late Holocene, did the site become a major base camp with a complete cross-section of the entire social community, and the inevitable midden deposits that resulted.

In terms of origin, the animals found in the bench deposits fall into two basic groups: 1) a large group of animals tethered to standing water or moist soils, collected in Coleto Creek or the floodplain deciduous forest along the creek valley; 2) a smaller group of xeric upland animals collected from open, well-drained habitats, possibly at some distance from the site. This breakdown reflects the basic biological rule that amphibians tend to live in bottomlands, fossorial rodents in xeric uplands (Busch *et al*. 2000).

Water-Tethered Fauna

Many of the animals in the bench deposits are tethered to standing, or in some cases, slow-moving water. The gar, small fish, aquatic turtles (Emydidae, Kinosternidae), larger frogs (bullfrog, Rio Grande leopard frog) and water snake (*Nerodia*) would have been found in the water and dependent on a permanent water source. The other amphibians (smallmouthed salamander, cricket or chorus frogs, toad) would have been found near, and at times in, lentic water bodies. Amphibians both absorb and lose water through the skin and must stay in humid or wet habitats. The reproductive cycle of amphibians such as frogs and smallmouthed salamanders depends on laying eggs in water, usually in closed depressions such as floodplain ponds or vernal pools that are small enough and isolated enough to lack a fish population that might prey on the eggs (Petranka 1983). The presence of abundant algae or other submerged vegetation is also important as a shield against predation (Holomuzi 1989). Small closed water bodies are generally less abundant on the Coleto Creek floodplain today. There are large, deep pools

in the creek, but these have major fish populations. Bragg (1949:23) says that *Ambystoma texanum* eggs are never laid in water more than one foot deep, and usually in water not more than four inches deep. The contemporary floodplain sediments are often too sandy to retain water in closed depressions, except in the main channel of the creek itself. Chapter 4 showed how the floodplain sediments in the late Pleistocene were much more silt- and clay-rich than today, and the reconstructed hydrologic system for Coleto Creek in the Late Pleistocene portrays a sluggish, meandering, muddy stream that probably would have created small oxbows or cutoff sloughs with clay bottoms that would hold water and provide good breeding ground for an abundant community of amphibians. Rainfall during the Younger Dryas is believed to have been more evenly distributed throughout the year, less seasonal than today, with greater rainfall during the winter, reduced evaporation rates due to lower temperatures, more constant aquifer recharge, and less flashy stream discharge than today. Groundwater spring discharge would have accounted for a much higher (and thunderstorm runoff lower) proportion of stream discharge during the Younger Dryas. A climatic regime like this would have kept floodplain pool levels high during the winter and early spring. *Ambystoma texanum* breeds and lays eggs from late January until April in Texas (Garrett and Barker 1987:53; or in March in some of the more northern states), so the presence of a robust salamander population attests to the stability of lentic water bodies on the floodplain in winter and early spring. This reconstruction is entirely consistent with the evidence already assembled from diatoms and freshwater sponges (Chapter 7), aquatic snails (Chapter 8) and peaclams and freshwater mussels (Chapter 9). No salamanders were found during the pre-inundation ecological survey done in 1975-76. Whether they are truly extirpated in the Coleto Creek Reservoir area or whether sampling was simply inadequate is unclear.

In addition to these animals that were either outright aquatic fauna or at least heavily water-tethered, there are others that prefer moist to marshy soil. The fossorial pocket gophers and Eastern mole require moist (but not saturated or flooded) soil for digging. If these animals were found on the floodplain, it would have been in the somewhat higher, better drained, open unsaturated parts. Alternatively, if the climate was wet enough, these animals might have been found on the Beaumont and Lissie terraces, and may never have entered the floodplain. Gophers tunnel where they can practice underground herbivory of forbs, grasses, tubers and the like. Basically, they are ground cover-eaters, and ground cover is generally lacking in closed-canopy deciduous floodplain forest, so unless there were openings in the floodplain woodland, they might have been found on the adjacent Quaternary terraces instead. Moles are insectivorous and could have been found in either topographic situation.

In Chapter 4, evidence for cyclic bedding was presented. The grain size of the floodplain sediments varied cyclically throughout the Younger Dryas and early Holocene, and at times, the floodplain may have been too fine-grained for pocket gophers and moles, displacing these populations up onto the adjacent terraces. During coarser-grained intervals, these populations might have expanded back onto the floodplain again.

The other moist soil fauna are the small fossorial snakes, *Virginia*, *Storeria* and/or *Diadophis*. These are typically found in marshy habitats in the Midwest and eastern U. S. Likewise, raccoons are usually found close to water, although they can be seen at night foraging in all kinds of habitats more distant from water sources. Regarding the contemporary environment, the pre-inundation ecological survey says

> The creekside environment probably supports the most diverse and abundant herpetofauna of any habitat on the site. Half the snakes collected are found primarily near water. The creek and its moist immediate environs harbor several aquatic turtles and anuran amphibians. During the spring and early summer after periods of rainfall, temporary and semi-permanent ponds and roadside ditches serve as breeding sites for a variety of frogs and toads. Nine of the 11 species identified onsite prefer these breeding habitats to the larger, more permanent creeks. Predatory aquatic snakes can also be found in these temporary habitats (Espey, Huston and Associates 1976:3-5).

Xeric Upland Fauna

The second group of animals in the bench assemblage is perhaps smaller in number but even more diverse. They are intriguing because most of them -- chiefly rodents -- represent rather arid-adapted species found somewhat farther to the southwest today. Many of them are species not reported from Goliad County today, but found in nearby counties to the southwest. The Northern grasshopper mouse, the Black-tailed jackrabbit, the longnosed snake (*Rhinocheilus lecontei*) and possibly the kangaroo rat (assuming it is *Dipodomys compactus*) fall in this xeric group, and perhaps the extinct giant tortoise should be included, too. The heteromyids and the grasshopper mouse normally require bare ground for dust bathing, and may be found in disturbed habitats with disclimax vegetation. A few other species (least shrew, hispid pocket mouse, hispid cotton rat, Eastern cottontail, vole and possibly the uncertain woodrat species) are also upland prairie species, but have more cosmopolitan distributions.

Today, the Guadalupe River is the approximate boundary between the Texan biotic province and the Tamaulipan province to the south. As a result, several of the vertebrates found in the bench deposits are species pairs with parapatric distributions that make it difficult to determine which species is present. Examples are the *N. micropus-N. floridana* species pair, the *P. leucopus-P. maniculatus* species pair, or *the S. audubonii-S.*

floridanus species pair. During the Younger Dryas, with higher and more equable rainfall rates, this boundary was likely displaced to the southwest of its present position. This means that animals like the Northern grasshopper mouse or the Black-tailed jackrabbit might have been found even farther away from Berger Bluff than today. It suggests that the predator who introduced the prey animals to the site had a large foraging radius. It also adds a bit of disharmony to the composition of the fauna. The Northern grasshopper mouse is probably the only species in the fauna that is slightly extralimital, however, and it is recorded from Bee County. The extinct species and disharmonious taxa that are characteristic of the late Pleistocene (Graham and Lundelius 1995) are mostly lacking from the Berger Bluff bench fauna.

Berger Bluff Vertebrates: A Reclusive Fauna

What characteristics tie together the animals found in the Berger Bluff species list? Most of them are small, most probably less than 200-400 g in live weight. The extinct giant tortoise, the raccoon, and whatever species (deer or antelope perhaps) might be represented by the handful of large mammal bone fragments are the largest animals, but most are small, regardless of whether they are mammals, birds, fish, or herptiles.

Many of the species in the list are reclusive, cryptic, nocturnal and fossorial. McWilliams and Bachmann (1988:68) remark "Adult *A. texanum* are fossorial and are conspicuous to most human observers only during early spring when they migrate on the soil surface towards ponds where they breed and lay their eggs." Other fossorial species include the giant tortoise, Eastern mole, pocket gopher, vole, least shrew, pocket mouse, kangaroo rat, Northern grasshopper mouse, and the small fossorial snakes (*Virginia*, *Storeria* or *Diadophis*). Woodrats and toads might be considered semifossorial. In fact,

nearly every terrestrial animal in the list takes refuge either in a burrow or a den (raccoon, woodrat) of some sort

Archeologists tend reflexively to equate "fossorial" with "intrusive," but in fact, nocturnal-fossorial animals are highly adaptive prey for human foragers. Animals that forage at night take refuge in burrows that, if they can be located and assessed for occupancy by the forager, essentially serve as traps for the prey. Occupied burrows can be recognized by fresh dirt, tracks, fecal pellets or grass clippings. Some species that use scent-marking may be detectable by odor. An animal confined to its burrow can easily be dug out with a digging stick. Animals that forage at night usually have eyes adapted to dim light and the accounts of wildlife biologists show that they are usually confused and disoriented when evicted into sudden bright daylight. The accounts also mention that many of them can easily be caught by hand. A couple of digging sticks, a dog, and a pack of eager children are all the technology needed to collect most of the terrestrial species. The small fish could be collected by seining, and the small birds by fiber snares. Deadfalls were probably not used because there is no good local source of rock slabs.

The reptiles and amphibians are particularly vulnerable as human prey. These animals are *poikilotherms* (the term *ectotherm* is also used), or cold-blooded animals. Pokilotherms are often at a disadvantage when preyed upon by endotherms (although sometimes the predation goes the other way). Salamanders or snakes evicted from their burrows in the cool of the early morning can be expected to be sluggish and easily captured. In addition, because of their physiology, amphibians and reptiles are not adapted to sustain rapid bursts of energy even when at temperature equilibrium. According to Pough,

> …aerobic metabolism accounts for only a small portion of the total energy used to sustain high levels of activity… The consequent depletion of cellular energy stores and accumulation of lactic acid in tissues leads to rapid exhaustion. Many reptiles and amphibians are completely exhausted by 3-5 min of maximum activity and may require several hours to return their tissue to resting levels of lactic acid (Pough 1980:95).

Consequently, endothermic humans and dogs have the upper hand when hunting and collecting these kinds of animals (sun-basking turtles are a familiar example). Antipredator defense mechanisms listed for the genus *Ambystoma* include "noxious skin secretions, parotoid glands, dorsum of tail glandular, immobile posture, body coiled," and several distraction mechanisms, such as tail lashing and wagging (Duellman and Trueb 1986:Table 10-1; see this source for a good discussion of predator avoidance for amphibians in general). Another distinct possibility is that amphibians were captured in pitfalls. Wildlife biologists studying the effectiveness of different censusing methods for amphibians have found that pitfalls are one of the most effective capture techniques for salamanders and other amphibians. This raises the intriguing possibility that the two small pits (Feature 6 and Feature 7) discovered in the bench deposits might have been amphibian pitfalls, either intentional or unintentional.

Most of the animals in the hearth deposit are cryptic, inconspicuous, and obtainable by turning over rotting logs, peeling loose bark off trees, kicking over brush piles or woodrat dens, or digging up burrows. This is low-technology foraging, and it is the sort of activity normally expended by groups of children and dogs accompanying women on plant-foraging trips. In anthropological terms, this would be an "embedded activity," where the principal goal is to collect plants, water, or firewood, but various small prey are taken whenever encountered. In optimal foraging terms, *search time* is minimized because it is an embedded task. The Internet hosts a number of online

"herping journals" maintained by amateur herpetologists who keep logs of their field trips. The standard method used to find herpetofauna in the field is to seek out trash piles and flip over pieces of tin or plywood, logs, old tires, and the like. Many of the species turned up this way are the same ones found at Berger Bluff. This practice is a perfect modern analog for Paleoindian herptile foragers.

The animals represented in the hearth deposit are variously capable of running, jumping (pocket mice and kangaroo rats), burrowing, slithering, swimming, and flying, and they are derived from both floodplain and upland (possibly at some distance) habitats. The forager responsible for the latrine deposit was capable of dealing with multiple behavioral modes and foraging in disparate habitats. This kind of opportunistic flexibility seems characteristically human.

The Hearth Deposit: What Does It Signify?

The hearth deposit, or microvertebrate bone bed, is a concentrated, spatially restricted deposit of small animals bone immediately adjacent to and slightly lapping onto Feature 5, a small patch of fire-baked floodplain sediment at the base of stratum 2B. Earlier in this chapter I considered three different models for the origin of this deposit. It does not fit the criteria for a fluvial lag deposit; it does not fit the criteria for a raptor pellet midden very well, and it seems to correspond best to the latrine area of a mammalian predator. In some respects it may fit the profile of a mustelid fairly well, but we know little about how such a latrine might appear archeologically. Considering all the evidence, I think the deposit corresponds best to the physical and taphonomic profile of a human latrine area (the appearance of possible human tooth pitting like that documented by Landt is especially promising for further study). My experience with prehistoric

human latrine deposits is limited to a very different kind of context at Baker Cave, but the latrine we excavated there (later analyzed by Sobolik) corresponds closely in size and degree of clustering to the bone bed at Berger Bluff, if one can imagine most of the organic constituents decayed away. All things considered, though, I think the strongest arguments for human agency are still the customary archeological criteria of close spatial association and the very limited, but definite evidence of burning on a few of the small animal bones. As I have said earlier, I do not think those bones were necessarily burned in Feature 5, but they are evidence of human involvement. I have also shown that essentially all the animals (or at least kinds of animals) in the hearth deposit appear as food items in ethnographies, in known human coprolites elsewhere in the borderlands, and as inclusions in midden deposits in Texas and elsewhere. What more evidence do we need?

At Hidden Cave, Nevada, Thomas (1985:382-383) makes a case for considering the site as a *diurnal way station* – a temporary stopping point visited for a few hours during the course of daily foraging trips, perhaps a place to collect spring water, check amphibian pitfalls, and look for riparian animals; a place usually visited only by foraging parties, not by the complete local community, and seldom or never for overnight stays; a place visited often, but with limited human impact, and only sparse accumulation of cultural debris. Such a place, with its human markers but little or no impact on the immediate habitat, would make an ideal spot for paleoenvironmental studies.

Comparable Sites

Berger Bluff is unusual, but it is not unique. The most relevant comparison is to the Aubrey site, where

> The identified small mammal bone distribution does not appear at all to be random… as there are multiple clusters, each comprised of (*sic*) multiple taxa. Each of the rabbit bones is near a hearth, as are the clusters of microtines, gophers and moles. Burned small mammal bone is also near the southern hearths, while the category "rodentia" is quite widely scattered….
>
> Burned snake and turtle are found almost exclusively with the southern hearths, with only three turtle fragments on the west edge of the block…. No burned reptiles were found in the northern area. Six of the ten fish bones are associated with hearths as well, also suggesting a use-related distribution. Overall, the evidence that small game was intensively processed at Aubrey is compelling (Ferring 2001:189).

In addition to the Aubrey site, there are several other Late Paleoindian or Early Archaic sites that have extensive assemblages of small animals in contexts that suggest a cultural origin: Baker Cave (Texas), the Stigenwalt site (Kansas), and Medicine Lodge Creek site (Wyoming) are examples, and there may be others, such as the Allen site (Nebraska).

Missing Taxa

Two small taxa, key markers of Pleistocene deposits, are apparently missing from the Berger Bluff assemblage: Masked shrew (*Sorex cinereus*), and Southern bog lemming *(Synaptomys cooperi*). Some other small mammal taxa still found in the area are also apparently missing: there are no sciurids of any kind (four species are resident at present, all diurnal), and short-tailed shrews (*Blairina*), rice rats (*Oryzomys*), pygmy mice (*Baiomys*) and harvest mice (*Reithrodontomys*) are not currently known from the collections. Any of these might be found with further picking of matrix or further examination of the unstudied lots. I have seen at least one small long bone (not reported here) that is an excellent match for *Reithrodontomys.*

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Chapter 11: Summary and Conclusions

Time sucks the meaning from many things, and the future finds the rind.

-- Wallace Stegner (1942, *Mormon Country*)

THE BENCH AT BERGER BLUFF

Berger Bluff (41 GD 30) is a nine-meter high sandy bluff on the southwest side of Coleto Creek, which forms the northeastern boundary of Goliad County here. The city of Victoria lies about 15.5 km to the east. The entire bluff is an exposed archeological site. The uppermost 2.5 m of deposits were excavated in the summer of 1979, approximately the lowest 2 m were tested during field visits between November, 1979 and April, 1980 (reported here), and the middle package of sediments, about 4.5 m thick, have never been investigated.

The present work is a multiproxy study of paleoenvironmental change during the transition from the Late Pleistocene to the early Holocene in the lowest package of "bench" sediments, estimated to date approximately 11,000-8500 radiocarbon years before present (RCYBP) or 13,000-9500 calendar years before present. The bench is so called because frequent and robust groundwater recharge during the Late Pleistocene is believed to have promoted steady groundwater seepage from the calcareous Goliad Formation bedrock buried under the valley wall, infiltrating the floodplain sediments with phreatic carbonate. The resulting weak carbonate cement has preserved the lowest

package of sediments from subsequent erosion and reworking by Coleto Creek as it cut down into its older sediments. The erosional bench that is the focus of this study consists of two major sedimentary deposits, stratum 1 and stratum 2. A third unit, stratum 3, lies above the others, has much less carbonate cement, and is much more eroded. It is really transitional between the Pleistocene sediments below and the Holocene sediments (strata 4 and 5) above, but is tentatively considered part of the bench deposit.

The age estimate for the bench deposits is based on a set of eleven radiocarbon assays (seven on wood charcoal, four on sediment humin; Table 5.1). None of these come from the uppermost 80 cm or lowermost 60 cm, so the endpoints of 8500 and 11,000 RCYBP are simply guess dates based on radiocarbon assays clustered in the middle part of the bench sediments. In terms of the European and North Atlantic climatic chronology, the six assays that are considered most reliable fall into the Younger Dryas and Preboreal periods (Fig. 5.6), but there is considerable accumulation of sediment above that point, and the most significant stratigraphic change, at the top of stratum 3, remains unassayed and its age can only be guessed to approximate 8500 RCYBP, or midway in the Boreal period. Sources of uncertainty and inversions of radiocarbon assays are discussed in Chapter 5. The boundary between the Pleistocene and the Holocene falls somewhere in the middle of the bench deposits (perhaps near the top of stratum 2?) but cannot be identified in section.

The Continental and Chronological Setting

At 18,000 RCYBP, the Laurentide ice sheet covered the entire northern extent of the North American continent, including essentially all of Canada (Dyke 2004:377), blocking frigid polar air from entering the continental interior. By 11,000 RCYBP,

postglacial warming had removed about 40% of this ice, opening a narrow ice-free corridor, but large air masses were still blocked (Dyke 2004:Fig. 5, 391). By 10,250 RCYBP, the Cordilleran ice sheet was nearly gone, and the western side of the continent began to open to polar air masses (Dyke 2004:393). The Laurentide sheet continued to retreat, despite the fact that cooling during the Younger Dryas actually led to readvance of some of the smaller alpine ice sheets. By 8500 RCYBP, about 65% of the ice sheet had been removed and ice had withdrawn from the United States, but the eastern half of Canada was still covered (Dykes 2004:398).

Before 10,250 RCYBP, the enormous mass of the Laurentide ice sheet not only blocked Arctic air from entering the continental interior, it also displaced the jet stream far to the south of its current mean annual position. Under modern climatic conditions, the jetstream is responsible for steering moist Pacific air into Texas from Baja California in the winter. This winter rainfall tends to be prolonged, gentle, and geographically widespread, often lasting for several days, rather than concentrated into short, intense bursts. This kind of rainfall produces maximum groundwater recharge and minimum runoff. In contrast, the intense convective thunderstorms that result from collision of fast-moving Arctic cold fronts with inland-moving moist Gulf air in the spring and fall here in Texas tend to produce rapid, intense flashy runoff (Figs. 1.43, 1.44) that moves out of the catchment before it can contribute much to aquifer recharge.

During the Younger Dryas, weather patterns may have resembled today's wintertime weather more or less year-round. Southward-plunging Arctic northers were absent, blocked by the ice sheet. Pacific moisture from the west was probably present more nearly year-round, and lower Gulf water temperatures suppressed the amount of

Gulf moisture invading the interior of the state. The ratio of Pacific to Gulf atmospheric moisture was probably much higher in the Pleistocene than today, and aquifer recharge was probably constant year-round, unlike today's strongly seasonal pattern. As the Holocene developed, the zonal (west to east) atmospheric flow characteristic of the Pleistocene gave way to a pattern in which meridional (north-south) flow became dominant during certain seasons of the year, with cold, dry air moving southward in high pressure cells, or warm, moist Gulf air moving northward into low-pressure cells.

The Gulf of Mexico is a key factor in regional climate, especially for the Texas coastal plain. The Gulf shoreline is 82 km away from Berger Bluff now, but at the late Glacial maximum, when so much oceanic water was locked in continental ice sheets, sea levels were much lower and the shoreline was an additional 88 km away. At 8500-11,000 RCYBP, the level in the Gulf was about 40-75 m lower than at present.

Throughout the transition from the Late Pleistocene to the early Holocene, total annual insolation at latitude N29° was above present levels (fig. 1.2, A), late summer insolation was above present levels (and increasing steadily, Fig. 1.3), and winter insolation was below present levels (Fig. 1.2, B). The seasonal contrast in insolation peaked well above present levels at 10,000 RCYBP (Fig. 1.5, A). Despite this potential for global warming, regional temperatures lagged behind insolation because of the influence of the major ice sheets. As the Laurentide ice sheet continued to melt in the early Holocene, draining into the Gulf through the Mississippi River, four very important final flood events at 9970-9870, 9740-9660, 9450-92,90, and 9160-8900 RCYBP occurred (Aharon 2003). These helped to keep water temperature in the Gulf cool despite the solar maximum at 10,000 RCYBP, and this may have been the critical factor

keeping regional climate cool well into the early Holocene. I have argued elsewhere that major geomorphic changes in the Coleto Creek catchment were probably delayed some 1500 years into the Holocene as a result of the suppressing effect of these late meltwater events. Hurricanes form in the Gulf of Mexico when water temperatures of 26° C are sustained for several months, usually from July to October. Average Gulf temperatures were probably not warm enough to sustain hurricanes until well into the Holocene, perhaps after 9000 RCYBP, although uncertainty remains about the date. Once Gulf water was sufficiently warm, however, early Holocene hurricanes may have been more severe even than contemporary ones, because late summer insolation remained at peak levels until 8000 RCYBP and later (Figs. 1.3, A, 1.4). These early Holocene hurricanes had the capacity to do enormous amounts of geomorphic work in any catchment that lay in their path.

Archeological sites are usually poor locations for doing paleoenvironmental studies because of the propensity of humans for modifying their immediate habitat. However, early in its history, Berger Bluff was never a base camp, and in fact this locality was not used as a base camp by large numbers of people until late in the Holocene. The sparse cultural debris and features buried in the bench deposits indicate that throughout its early history, the site (or at least the part of it that is preserved now) was visited only briefly, probably by small groups foraging outward from more permanent camps located elsewhere. It seems clear that human visits to the site had minimal impact on the immediate habitat in this early part of its history, and there is no reason to suspect human impact has altered the paleoenvironmental profile that can be reconstructed from the deposits.

Substantive Findings

Some of the central paleoenvironmental questions asked in this project were: what was the moisture history of the site in the Younger Dryas and the transition into the Holocene? Was the Younger Dryas wetter or drier than the early Holocene? Can evidence of submillennial climatic cycles be recognized? Is there a local stratigraphic marker for the abrupt North Atlantic climate changes documented in the Greenland ice cores? Are there extinct or extralimital species?

Some of these questions could be answered and others could not. None of the proxy environmental indicators used in this project are particularly sensitive to temperature change, with the possible exception of the cold-water spring snail *Valvata tricarinata*. Absolute temperature changes can usually be assessed in continental interiors only with fossil insects, noble gas paleothermometry, or (in a very crude fashion), stable isotopes. Nevertheless, the sediments, snails, diatoms, vertebrates and (indirectly) freshwater mussels reveal a fairly cohesive and clear picture of the moisture history of the site, and indicate that during the Younger Dryas the catchment was much more well-watered than today, although experiencing a slight long-term drying trend. Groundwater recharge rates were much higher, and spring discharge much more significant. The ratio of phreatic to meteoric water in Coleto Creek runoff was probably much higher than today. Two kinds of data, diatoms and snails, were abundant enough to be examined with quantitative methods (correspondence analysis and cluster analysis).

Sediments and Stratigraphic History (Chapter 4)

Although present-day Coleto Creek is a bedload-dominated stream, from the Younger Dryas into the early Boreal period the creek was a suspended load-dominated stream. About 63% of the sediment in the bench is silt and clay. The presence of so much fine-grained sediment indicates that out-of-bank flooding was a fairly common occurrence, and floods were prolonged, not erosive in nature. There seem to be no instances of eroded or truncated strata. The creek banks were cohesive and the channel significantly deeper and narrower than at present, furnishing a good habitat for the large, mature *Amblema plicata* mussels found in the deposits. A steeply banked, meandering, muddy channel with a width/depth ratio of anywhere from 3:1 to 10:1 seems most probable. Alternating muddy and sandy zones appear conspicuously in the cutbank (Figs. 4.21, 4.22), and grain size analysis shows that cyclic variation in grain size (fig. 4.69) is superimposed on a slight coarsening-upward trend (fig. 4.70) that may represent climatic changes associated with regional warming.

Abundant phreatic carbonate (appearing in the form of matrix cement, rhizoconcretions, irregular pans, nodules, and encrustations on buried objects) is the result of more or less constant, active groundwater discharge from nearby calcareous Goliad Formation bedrock, recharged in turn by equable precipitation patterns in the catchment. Matrix cement makes up about 18% of the sediment by weight. Above stratum 2, phreatic carbonate is greatly reduced, suggesting that seepage was also reduced, and above stratum 3, there is a major change in depositional style from cyclic deposition in strata 1-3 to massive deposition in strata 4 and 5. Pockets of gravel and coarse sand appear near the top of the bench (stratum 2E), representing coarse-grained

bedload material lofted out of the channel and onto the floodplain surface by a major flood event. This flood event may have been one of the first hurricanes to enter south Texas from the Gulf as the Gulf waters warmed sufficiently in the early Holocene to sustain hurricanes. Alternatively, the event might have been triggered by one of the first Arctic cold fronts to penetrate south Texas after Laurentide ice retreat left the midcontinent to Arctic air. In either case, the reduction in carbonate and appearance of flood markers are clues signaling the onset of Holocene weather patterns and marking the crossing of a geomorphic threshold. Above this point, clay (and perhaps silt) content is reduced as massive accumulation of stratum 4 begins.

Moving upward through the stratigraphic section, as carbonate content diminishes, limited evidence for weathering in the form of microscopic sediment fissuring (Figs. 4.86, bottom and 4.87, bottom) and argillans (Fig. 4.93) becomes somewhat more common, indicating a long-term trend toward drying in the catchment.

The onset of Holocene conditions cannot be dated accurately. The top of stratum 3 is about 80 cm above radiocarbon sample AA 2831 (9880 ± 90 RCYBP), and the base of stratum 2E is about 43 cm higher than the sample, so it can only be said that the onset postdates that sample by some unknown length of time. I have somewhat arbitrarily estimated a date of about 8500 RCYBP, or sometime early in the Boreal period. In any case, it seems probably that the local onset of Holocene weather conditions was lagged about 1500 (?) radiocarbon years behind the end of the Pleistocene as marked in the Greenland ice cores, probably as a result of the regional buffering effect of Holocene meltwater spikes in the Gulf.

The cyclic bedding seen in the deposits may be due to submillennial climatic events, with the muddy units accumulating during wetter periods (see Fig. 4-100 for a proposed model), but it is difficult to demonstrate. Testing the hypothesis by looking for quantitative variation in biota like diatoms or snails is hampered by preservation gradients. Snails become infrequent with greater depth, diatoms with lesser depth, making it difficult to assess variation across the full range of strata.

Pollen and Wood Charcoal (Chapter 6)

Pollen is very poorly preserved and only the most decay-resistant taxa are left.. Most charcoal fragments are too small for identification. Composites, oak, cottonwood, willow, pecan and possibly Eastern red cedar are recognized among the pollen and macrofossil samples, along with isolated pollen grains of pine and sweetgum.

Diatoms and Freshwater Sponge Spicules (Chapter 7)

Four kinds of biosilica (diatoms, freshwater sponge spicules, chrysophyte cysts, and phytoliths) were found, but only the diatoms were studied systematically. The bench deposits have a taxonomically diverse assemblage of at least 65 species (Table 7.2), mostly from the lower part of the deposits. About half originated in aquatic habitats and about half are more drought-adapted species that can be found either submerged in water or in aerophilous, damp environments (mud, damp moss, or rocks). Most species are alkaliphilous and epiphytic. Many are commonly found attached to *Phragmites* stems, moss, or bryophyte mats. Cell counts and species richness peak in the sandy strata and tend to be reduced in the muddy strata (Fig. 7.4). The percentage of aquatic diatoms declines over time (Fig. 7.6). In general, diatom abundance and species richness show a

fluctuating but persistent decline from the bottom to the top of the bench, and drought-adapted species become more common. Sponge spicules also appear to become less common, although they were not studied quantitatively. This probably indicates that aquatic habitat quality was diminishing in Coleto Creek because of increasing flood force, low water levels, and possibly changing salt or alkalinity levels. How much of the upsection decline in abundance is due to taphonomic decay or changing sedimentation rates is unclear. Breakage of diatoms and sponge spicules also becomes more common toward the top of the section. Many, perhaps most diatom species found in the bench are rather catholic species with a global distribution. They are so eurytopic that it is difficult to extract any environmental interpretation from them. Correspondence analysis of the diatom data (Fig. 7.12) shows that each stratum has its own diatom signature, however, and the principal axis is interpreted as duration of saturation of the substrate. Fig. 7.12 shows the strata generally tend to move from saturated (right side of X axis) to drought-prone (left side) as successively higher strata are added. In summary, the strata largely differ from each other in composition, and the trend toward long-term drying clearly merges from the numerical analysis, but variations are not cyclic in nature. In fact, the two muddy strata (2A and 2C) are at the extremes of the axis. In this respect, the strata seem to fail the biological test as climatic in origin.

Snails (Chapter 8)

The bench deposits have a rather well-preserved and speciose snail fauna, at least 35 or 36 species (Table 8.11). Of the various proxy environmental indicators studied in this project, the snails probably gave the most useful and interpretable results. Microsnails, medium-sized, and large-bodied taxa each represent about a third of the species list. Some 25 or 26 species are terrestrial snails (10 cosmopolitan, eurytopic,

drought-adapted species and another 15 or 16 woodland species, including at least one slug), two species are amphibious, and at least eight are aquatic. Three different recovery methods were used: 1/4-inch screen (almost 9000 specimens, large and medium-bodied taxa), fine sieving of two 25 x 25 cm matrix columns (4905 specimens, all sizes, but especially microsnails), and selected levels from one entire excavation unit (all matrix passing the 1/4-inch screen, mostly microsnails and juveniles of larger taxa; Appendix 5, 818 specimens to date). The snails have a distribution that is exactly opposed to that of the diatoms – they decline in frequency with depth (Figs. 8.22-8.25). This seems to be mostly due to a preservation gradient. Heavy carbonate deposits in the lower part of the stratigraphic section resulted in severe shell breakage when sediment samples were processed.

Many of the terrestrial species (e.g., *Anguispira strongylodes, Euchemotrema leai, Gastrocopta contracta, Gyphyalinia umbilicata, Mesodon roemeri, M. thyroidus, Mesomphix friabilis*) are inhabitants of wooded floodplains, either in deciduous leaf litter or under downed wood. They are indicators of mature, deciduous riparian woodland covering the floodplain and adjacent valley slopes. This is a mesic to dry woodland fauna, but not a wet ground taxocene. A few other species (*Carychium mexicanum, Pupisoma dioscoricola*) are characteristic of wetter floodplains, and two *(Catinella vermeta, Pomatiopsis lapidaria*) are amphibious. In the bench *deposits Gastrocopta contracta*, a mesic-adapted species, occurs in moderate numbers while *G. pellucida*, a more xeric-adapted species, occurs only sparsely. In the modern snail fauna from the nearby Preiss Ranch, the ratio is reversed, and the xeric-adapted *G. pellucida* are dominant (Table 8.13).

Two Pleistocene marker species now extirpated from Texas (*Valvata tricarinata*, Fig. 8.96, and *Pomatiopsis lapidaria*, Fig. 8.7) are found in the bench deposits. Two other species now greatly reduced in geographic range in Texas (*Cincinnatia integra* and *Gastrocopta tappaniana*) also occur. Three species now characteristic of the Edwards Plateau and beyond (*Gastrocopta armifera*, *Glyphyalinia roemeri?* and *Mesodon roemeri*) are also found. Except for *C. integra* and *M. roemeri*, which are probably still present in the area as small remnant populations, these species have vanished from the area as result of northward and westward range contracts during the warming Holocene. The most significant extirpation is *Valvata tricarinata*, an aquatic snail characteristic of cold lakes and rivers in northern latitudes, or cold springs and ponds in the southern part of its range, where it is usually found in water no warmer than 15° C (59° F). It is a classic Pleistocene index fossil in alluvial terraces in Texas and the southern Plains. At Berger Bluff, it may have occurred in a nearby perennial cold-water spring maintained by constant discharge from the Evangeline Aquifer. Its extirpation from Texas could have been caused by rising groundwater temperatures, increasingly irregular spring discharge, or increasingly seasonal changes in hydrochemistry. The species of *Valvata* that live in the northwestern quadrant of the U. S. are found in waters with a high concentration of bicarbonate (HCO_3) relative to calcium (Sharpe 2002:Fig. 3), and it is possible that *Valvata* may not be able to tolerate a great deal of seasonal variance in solute composition. Increasing seasonality in the Holocene may have driven solute variability beyond the tolerance limits of the species. Other aquatic genera such as *Gyraulus* are solute generalists (Sharpe 2002:Fig. 5) and have not been extirpated.

Correspondence analysis and cluster analysis were used for numerical studies of the snail counts. Because 1/4-inch mesh and fines sieves capture different ratios of taxa,

these two kinds of samples were analyzed separately. Correspondence analysis accounted for only about 52-53% of the variance in the data, indicating that different taxa are not strongly clustered (either stratigraphically or horizontally). For the 1/4-inch mesh sample, the first axis extracted seems to represent aquatic and deciduous woodland taxa, and when the case scores are plotted vertically (Figs. 8.83 and 8.84), a pattern of irregular fluctuation superimposed on a trend of long-term decline is seen. The upward decline in the first axis seems to indicate long-term drying of the habitat. In the correspondence analysis of the fine-sieved matrix samples, the pattern is the same, but the first two axes are reversed. The first axis seems to represent dry woodland, the second axis aquatic and deciduous woodland taxa. Stratigraphic plots of Axis 1 show irregular fluctuation superimposed on a long-term increase in one unit (Fig. 8.94), with mostly irregular fluctuation in the other (Fig. 8.95). Again, this is taken to indicate a pattern of long-term drying and replacement of mesic deciduous woodland with dry woodland or reduced canopy cover in the catchment.

None of the case score plots show a consistent response to the stratigraphy as recorded in the profiles. In other words, the scores for the “mesic deciduous” axis do not show large positive spikes in the muddy units and negative spikes in the sandy units, as might be expected if the muddy units represent wetter climatic intervals. In all of the numerical studies, a trend toward long-term drying emerges more clearly than any climatic pattern related to the muddy and sandy depositional couplets. On the other hand, cluster analysis shows a fairly impressive amount of stratigraphic coherency for the different strata (Fig. 8.89), indicating that, just as in the diatom analysis, each stratum has its own distinctive snail taxonomic signature.

Freshwater Mussels, Sphaeriid Clams and Peaclams (Chapter 9)

Single and clustered valves of Threeridge (*Amblema plicata*, mostly large adults) and a single Giant Washboard (*Megalonaias nervosa*) fragment were found in the bench deposits, evidently as a result of human predation. Many of them are clustered on a buried surface in stratum 2A. A single Southern Mapleleaf (*Quadrula apiculata*) was found over 20 m downstream at about the same level as stratum 2A. All three species are often found in fairly deep water and can tolerate muddy bottoms and fairly turbid conditions, although they do not prefer sluggish or turbid water. Threeridges are particularly tolerant of high suspended loads. Peaclams (*Cyclocalyx?*), which are often characteristic of deep water and tolerant of turbid conditions on mud or sand bottoms.

The *Amblema plicata* are mostly large individuals and many may have been as much as 18-19 years old when they were collected from the creek. This may indicate that the recurrence interval for major floods was greater than 18-19 years. These underlie and predate the major flood event in stratum 2E. The Giant Washboard is a deep water species, possibly imported from the Guadalupe River or from lower reaches of Coleto Creek. It is a somewhat larger than average individual, probably 22-23 years old or somewhat younger. Ethnographic studies show most shellfish collecting is done by women and children, and that was probably the case at Berger Bluff.

Vertebrates (Chapter 10)

Animal bone is well-preserved in the bench deposits except for mechanical breakage, and (tentatively) appears to have a preservation gradient (Fig. 10.3) similar to

that of the snails. At least 31 taxa appear to be present (Table 10.1). Most are small animals, regardless of whether they are fish, birds, amphibians, snakes, lizards, or mammals. Reptiles and amphibians are especially well represented.

One probable extinct species is represented – giant tortoise, *Gopherus hexagonatus*, tentatively recognized from a single small carapace fragment (Fig. 10.28) recovered 50-55 cm below radiocarbon sample AA2831 (9880 ± 90 RCYBP). It shows no evidence of reworking and appears to be contemporaneous with the rest of the fauna.

There are two basic categories of animal bone in the bench deposits: *ambient fauna*, or isolated bone fragments scattered throughout the deposits representing environmental "background noise," and the *hearth deposit*, a concentrated microvertebrate bone bed adjacent to Feature 5, a small fire-baked patch of floodplain sediment. The ambient bone occurs in low density and is not abundant enough for numerical analysis (except perhaps in bulk matrix samples from N109 E96, where extraction and analysis is incomplete). The hearth deposit is tentatively interpreted as an abandoned human latrine deposit, with the microvertebrates originating from decomposed, no longer visible coprolites. The logic behind this interpretation (and other competing models: fluvial lag deposit, raptor pellet midden, mustelid latrine) is discussed at length in Chapter 10 and the reader is referred there for further details.

The animals found in the bench deposits are mostly small, reclusive and often fossorial, with a heavy emphasis on amphibians and rodents. Regarding habitat preference, there are two basic groups:

1) A large group of riparian floodplain animals tethered to standing water or moist soils. These include species found in standing water (gar, small fish, aquatic turtles, bullfrog, Rio Grande leopard frog, water snake) or found near, and at times in lentic water bodies (smallmouthed salamander, cricket or chorus frogs, toad), and the fossorial pocket gophers, eastern mole, and small fossorial colubrid snakes (*Virginia*, *Storeria* and/or *Diadophis*) found in moist or marshy soil.

2) A diverse but somewhat smaller number of animals from xeric upland habitats (giant tortoise, Northern grasshopper mouse, Black-tailed jackrabbit, longnosed snake, kangaroo rat) or cosmopolitan upland habitats in general (not necessarily xeric), such as the Least shrew, Hispid pocket mouse, Hispid cotton rat, vole, and possibly woodrat (*Neotoma* sp.). There are also some species that cannot be assigned to either group because of identification ambiguities (small birds, *Peromyscus* sp., etc.).

The many amphibians in the fauna suggest the presence of small closed water bodies on the floodplain, since most amphibians lay their eggs in floodplain ponds or vernal pools that are too small and shallow to invite fish predation on the eggs. The finer-grained sediments found on the floodplain in the Younger Dryas and Preboreal should retain water better than the porous sands found there today. Flatter floodplain topography, the presence of shallow closed depressions, more continuous tree canopy and more robust groundwater supply all combined to maintain humidity levels and lentic water capacity in the riparian corridor much higher than today.

PALEOENVIRONMENTAL SUMMARY: COLETO CREEK CATCHMENT IN THE YOUNGER DRYAS-EARLY HOLOCENE

The bench sediments and the biological organisms preserved in them present a coherent picture of the catchment during the Younger Dryas and Preboreal. The floodplain in the vicinity of the site was probably wider and flatter than today, because the extensive, sloping, sandy terrace deposits on the north side of the creek appear to be more recent and would have been absent in this earlier period. Deposition was dominated by suspended load from Coleto Creek, so the floodplain was flatter and muddier, with much better water retention capacity. Coleto Creek was narrow, deeper, more steeply banked and sinuous, and streamflow was less variable because groundwater seepage accounted for a higher percentage of runoff. Despite the increased presence of phreatic water, streamflow may have been more turbid simply because of increased ground cover in the catchment. At the site itself, deposition alternated between muddy and sandy units over time spans amounting to some unknown number of centuries, either because of the natural meandering of the creek toward and away from the site, or because of submillennial climatic cycles. Significant numbers of pocket gophers and eastern moles were found, so if the floodplain was at times too wet or fine-grained to provide good habitat, they must have found higher ground somewhere in the floodplain or nearby. A small perennial spring or seep existed near the site, harboring cold spring snails such as *Valvata tricarinata* and other mollusks. Muddy ground and seeps were probably widespread in the valley, attested to by many of the mud-dwelling diatom species. Extensive, deciduous tree canopy was present in the riparian corridor, creating a heavy carpet of leaf litter on the floodplain and valley slopes, attested to by many litter-dwelling snail species. Mature deciduous forest also produces abundant downed wood, and this,

too is indicated by many snail species and some of the reptiles and amphibians that customarily use rotting logs and branches as refuges. Humidity levels in the riparian corridor would have been much higher than today, both because there were so many water sources on and in the ground, and because during the growing season the tree canopy would have retained moisture, cut wind velocity, and reduced ambient temperatures. Even in wintertime, with no foliage, humidity levels likely would have been higher than today.

Flash flooding was rare or absent until early in the Holocene, and consequently slower-growing tree species with longer maturation rates could have grown in the floodplain, in a zone that today is dominated by fast-growing species with high turnover rates. This is also attested to by the presence of species preferring downed wood, as noted above. Living under or near this mature canopy was an interesting array of animals, including many water-tethered amphibians, reptiles, fish, mussels, and snails. Discharge in Coleto Creek was equable, less seasonally variable than today, and violent flooding caused by hurricanes or thunderstorms triggered by invading Arctic airmasses was absent, allowing freshwater mussels as well as trees to reach full maturity. Flooding due to widespread convective thunderstorms was probably also absent, or at least rare.

Less information is available about the upland Quaternary terrace surfaces adjacent to the riparian corridor. Along with the many mesic-adapted organisms in the bench deposits, there is a secondary component of more xeric-adapted biota that must have come from this upland habitat. There are several eurytopic diatoms, snail species (e. g., *Oligyra orbiculata, Praticolella pachyloma, Rabdotus* sp., *Helicodiscus singleyanus, Gastrocopta pellucida*), mammals (*Onychomys leucogaster, Lepus californicus,*

Dipodomys) and a snake (*Rhinocheilus lecontei*) that can tolerate fairly dry conditions. The diatoms and snails must have come from sheetwashing of open valley slopes leading to the floodplain, but many of the vertebrates may have been introduced to the site from a considerable distance by human predators.

It is clear that at least the second half of the Younger Dryas and the early part of the Holocene were wetter than today, but experiencing a slow, long-term drying trend. The drying trend is sufficiently subtle that it is apparent only from the various numerical analyses that were done on sediments, diatoms and snails. The conspicuous reduction in phreatic carbonate at the top of the bench suggests an acceleration of this drying trend some unknown amount of time after 9880 RCYBP (AA2831), perhaps not long after the last Gulf meltwater pulse at 9160-8900 RCYBP. Shortly after this, a major flood event in the Coleto Creek drainage left pockets of gravel and stringers of coarse sand and pebbles strewn across the floodplain, furnishing a conspicuous stratigraphic marker that probably signals the onset of Holocene weather patterns in earnest (Fig. 11.1). It may well have been one of the first hurricanes to cross the south Texas coast.

However, I believe this flood event did far more than simply transport coarse sediment. It may have stripped out and destroyed the mature riparian habitat upstream. It may have irrevocably altered the hydrology and biology of the floodplain, removing breeding habitat for amphibians, displacing and destroying freshwater mussel beds, and removing the mature forest canopy that sheltered a wide range of snails, mammals, reptiles and amphibians. It is quite possible that the entire riparian habitat in the Coleto Creek catchment could have been stripped out and left unable to reproduce itself in a rapidly warming and drying Holocene climatic regime. It may well be that restoration of

habitat in the valley did not approach anything like its Younger Dryas character until late in the Holocene.

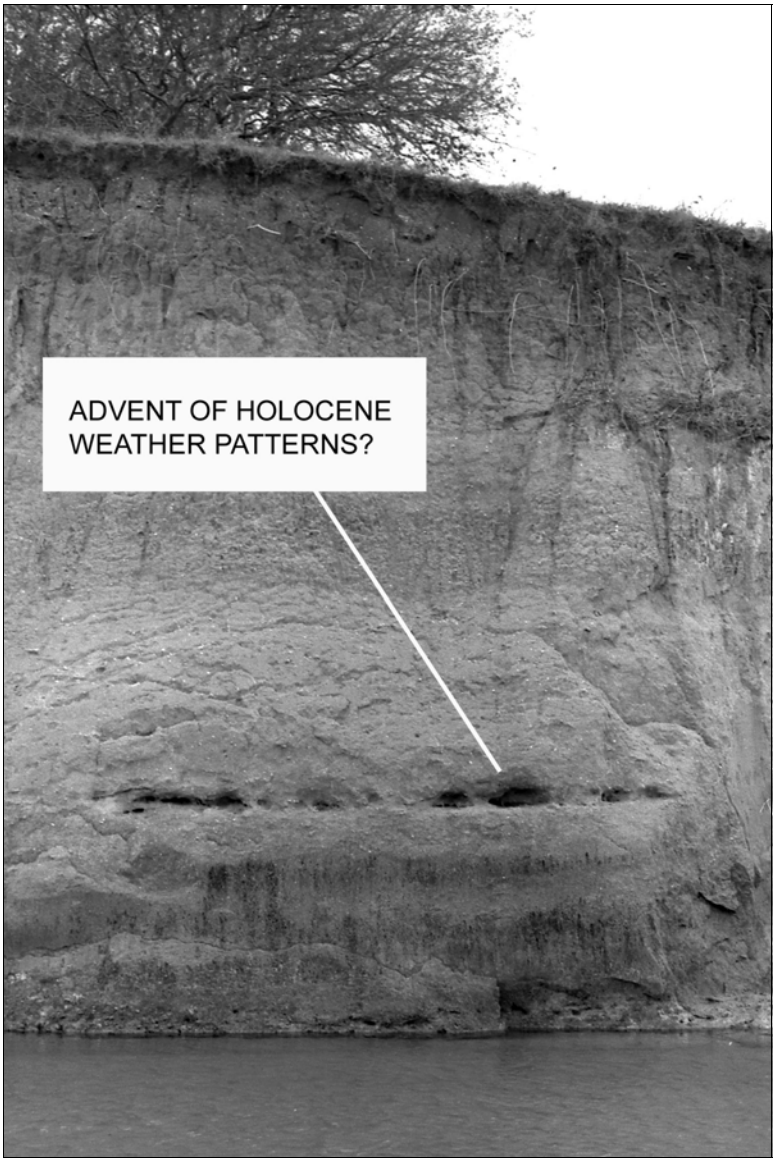

Figure 11.1. Advent of the Holocene at Berger Bluff. Looking southwest at Berger Bluff. The voids are washed-out gravel pockets at about the same stratigraphic level as stratum 2E in the bench area, out of view to the left. This is a relabeled version of Fig. 4.20

This is probably impossible to prove with the data at hand, because essentially no sampling was done above the flood markers, except for a column of phytolith samples (now missing). Indeed, the Scope of Work for the bench project did not provide for sampling this part of the section. Still, it remains a useful hypothesis that could be tested by future research. As hurricanes and violent flooding became increasingly common on the coastal plain in the early Holocene, mature riparian habitat was probably stripped out of all of the small catchments inland from the coast, one by one as the vagaries of storm tracks prescribed. I would argue that these floodplain forests could not regenerate in a Holocene climatic regime, although there may have been some limited regeneration late in the Holocene. I suspect that although incremental drying undoubtedly played a role in early Holocene environmental control, the truly significant changes were due to the *geomorphic work* done by increasingly flashy discharge regimes. Geology destroying biology, if you will (cf. Starkel 2992). In my view, the first hints of an approaching geomorphic threshold are provided by the coarse-grained deposits in stratum 2E, and the threshold is finally crossed at the top of stratum 3. The large rivers (Nueces, San Antonio, Guadalupe, Navasota, Brazos) passing through the region would have been buffered from this kind of *habitat deletion* by their large size, which tends to smooth out flood peaks. As local hunter-gatherer populations found riparian habitat increasingly disrupted in small tributary catchments like the Coleto Creek drainage, they would have turned to the larger river valleys, where they could have found the same resources no longer surviving in the small catchments. The chief result might have been a movement of local populations out of small coastal plain catchments and concentration in the larger river valleys.

COMPARISONS WITH OTHER SITES

Older texts on Pleistocene environments often portray the Late Pleistocene as cold and dry. Cooler temperatures lowered evaporation rates, leading to reduced humidity and precipitation in many parts of the world, with massive loess sheets as a testament (Menking *et al*. 2004). This image is part reality and partly lack of research in tropical and subtropical latitudes. However, the acceleration of paleoenvironmental research in the last two or three decades has led to a new appreciation for regional variability, not just on a continental scale, but variability within regions the size of the state of Texas. We now know that antiphasing has been a common feature of Quaternary climates, and dry periods in one area may correspond with wet periods in another. Some climatic changes may have been time-transgressive. Below, I review the literature from Texas, New Mexico, and northern Mexico, with emphasis on moisture history. These regions are relevant because much of the weather in Texas probably arrived from the west during the Pleistocene. Most (but not all) of the sites reviewed in the Southwest and northern Mexico have evidence of wet conditions in the Late Pleistocene and early Holocene, commonly attributed to southward displacement of storm tracks by latitudinal movement of the jet stream (Benson, Kashgarian and Rubin 1995; Metcalfe *et al*. 2002:99; Enzel, Wells and Lancaster 2003).

Paleoenvironmental Sites in Texas

Paleoenvironmental sites in the Guadalupe-San Antonio river basins were reviewed in Chapter 2. The locations of some of the principal sites are shown in Fig.

1.26. The most useful site for comparison is Hershop Bog in Gonzales County, which I have reviewed at some length in Chapter 2 (see discussion and Figs. 2.13-2.17).

Hershop Bog

The lower part of the pollen core, the "birch pollen zone," appears to match the time span of the bench deposits. River birch is a riparian species growing where annual rainfall ranges from about 71.5-162.0 cm. Riparian tree pollen peaks in the Younger Dryas, then nearly vanishes at about 9171 RCYBP; upland trees reach a minimum at about 8500 RCYBP. Species richness for all pollen types declines throughout the Younger Dryas, reaching a minimum at about 8500 RCYBP (Fig. 2.14, A). Declining tree pollen counts through the Younger Dryas at Hershop Bog probably the same regional drying seen in various numerical analyses from the bench deposits at Berger Bluff. Given the limitations of the sampling interval and the limitations of absolute age control at both sites, the pollen record at Hershop Bog seems consistent with the paleoenvironmental reconstruction for Berger Bluff, but there is a real need for reanalysis of this site, coupled with application of modern dating techniques.

Richard Beene Site

At the Richard Beene site, snail samples (samples 18-23) from the Elm Creek C horizon and Perez Paleosol appear partly contemporaneous with the period of concern, but Raymond Neck interprets precipitation as "low to moderate, and possibly seasonal" (see discussion in Chapter 2). Soil carbon from C_4 plants actually reaches a minimum at about 11,500 RCYBP, then increases to a peak in early part of the Younger Dryas, declines until 10,000 RCYBP, then shows a small increase (Nordt *et al*. 2002:Fig. 3). In

any case, by the earliest part of the Younger Dryas, the local grasslands appear to have had proportions of C_4 plants within the range of variation characteristic of the first half of the Holocene, but considerably less than at present (but photosynthetic pathways do not directly address the issue of moisture).

Winston's Cave

See Chapter 2 for discussion. Tree pollen drops to a minimum between 9900 and 9000 RCYBP, then generally increases after that (Hudler 2000:Fig. 4-22), which is contrary to most of the other evidence presented here.

Wilson-Leonard Site

Collins (1998:127) recognizes marshy conditions in unit Ic1 at 11,000-10,600 BP and increased effective moisture. Bousman (1998:164-165; Fig. 8-1) tentatively suggests a change to somewhat drier conditions and a reduction in tree cover during the transition from Unit I to Unit II at about 9550 BP. Aquatic snails are scarce, but most of the few examples recovered occurred in units I and II. The lowest levels with preserved shells (levels 32-39) indicate woodland with downed wood and relatively high soil moisture (Shaw *et al*. 1998:1570). The earliest surviving phytolith assemblages, at about 10,000-9500 BP, suggest more closed canopy woodland with cooler and more mesic conditions than present. At 9500-8700 BP, xeric-adapted short grasses become more common (Fredlund 1998:1649).

Horn Shelter No. 2

Prochnow's study of slackwater alluvial deposits in Horn Shelter includes 15 different stratigraphic units from the period of interest (units 1 to 14, assayed at 10,150 to 8440 RCYBP; Prochnow 2001:Fig. 26) and indicates infrequent flood deposits and low severity of flooding during the Younger Dryas (11,000-10,000 RCYBP). He finds more frequent flooding, with moderate severity, from 10,000-8000 RCYBP, then no record from 8000-5000 RCYBP (Prochnow 2001:Fig. 38). The Younger Dryas deposits are characterized by roof breakdown and less alluvium than is currently being produced by the Brazos River. Prochnow attributes the scarcity of Younger Dryas alluvium to aridity. Since the Brazos River heads on the Southern High Plains, the dry interval recognized by Holliday (2000, see High Plains section below) at 10,900-10,200 RCYBP may be responsible.

Fort Hood, Carbon Isotopes

The Late Glacial Jackson Alluvium at Fort Hood supported 50-60% trees and C_3 grasses, 40-50% C_4 grasses, indicating a cool and/or wet climate. The Georgetown Alluvium at 11,000-8000 BP represents a transitional phase to warmer and drier Holocene climate, with 50-60% C_4 (warm season) grasses; after 8000 BP, 65-70% C_4 grasses prevailed (Nordt *et al*. 1994:117). A gradual shift to warmer and drier conditions is proposed.

Aubrey Site

The Aubrey site has a pollen record, but it is no younger than 13,260 RCYBP. According to Raymond Neck, snails from the pond deposits indicate that the climate at 11,000 RCYBP was cool, with moderate precipitation and effective moisture and relative humidity classified as "moist." Warming conditions during the Younger Dryas resulted in warm temperatures, low precipitation, and effective moisture and relative humidity classified as "dry" by 10,300 RCYBP. Unfortunately, there are no records for the remaining three centuries of the Younger Dryas or for the Preboreal.

Hall's Cave

Samples from about the 120-150 cm level, or 8630 ± 60 to 10,310 ± 70 RCYBP (Cooke 2005:Table 2-1) in Hall's Cave correspond to the interval of interest. Hall's Cave has no detectable Younger Dryas temperature signal in the fauna. A moisture index provided by the *Notiosorex/Cryptotis* ratio shows increasing aridity beginning at about 11,310 RCYBP and peaking in the mid-Holocene at about 5400 RCYBP (Toomey 1993:Fig. 40). Several mesic-adapted species (*Ambystoma* sp., *Scalopus aquaticus*, *Blarina carolinensis*, *Microtus ochrogaster*, *Pitymys pinetorum* and others) persist until the mid-Holocene, when they are extirpated around 4200-5750 RCYBP (Toomey 1993:451). Remarkably, over 500 *Ambystoma* vertebrae are present in the catalogued material alone (Toomey 1993:149).

Although both Berger Bluff and Hall's Cave show a drying trend during the period of interest, the histories of these two sites at opposite ends of the Guadalupe River

basin are different. At Hall's Cave the environment is fairly dry even before the Younger Dryas, then becomes even drier right through to the mid-Holocene. At Berger Bluff, the environment is wet but drying, then altered drastically by the crossing of a geomorphic threshold.

Mustang Springs

Stratum 1 fines upward and resulted from high-energy spring discharge and/or runoff, documenting a period of cooler temperatures and higher precipitation, but its age is unknown, aside from being older than the overlying Stratum 2. Stratum 2 dates from about 8080 RCYBP to 10,130 at the base. The lowest levels have diatoms from cool, deep, lentic water, succeeded by an alkaline marsh after 10,000 RCYBP, then more cool, deep lentic water from about 8500-8000 RCYBP. After 8000 RCYBP, the pond becomes mostly shallow (Meltzer 1991:241-242). Stratum 3 records the onset of the Hypsithermal.

Southern High Plains

Lakes changed to marshy conditions at various times over the span 10,500-9000 RCYBP. Regional drying and widespread eolian sedimentation occurred between 10,900 and 10,200 RCYBP (spanning most of the Younger Dryas). Carbon isotopes suggest the region was somewhat cooler during all or part of the span 10,000-8000 RCYBP (Holliday 2000:8), with the onset of Holocene warming at 8000 RCYBP. Among the playa lakes studied by Holliday, Hovorka and Gustavson (1996:Table 3), there are eight lacustrine mud samples with assays between 10,650 and 8640 RCYBP. The dry interval spanning most of the Younger Dryas is not recognized at Berger Bluff or at most of the other sites

reviewed here, except Horn Shelter, farther downstream on the Brazos River. This may be an example of regional contrasts in climate patterns, but it needs explanation.

Diamond Y Cienega

Although the oldest radiocarbon assay from this Pecos County pollen site is 9570 ± 80 RCYBP, the record for the analyzed core (Core 3) begins at 6730 ± 40 RCYBP. Therefore, the record here does not begin until a couple of millennia after the period of concern at Berger Bluff. However, it is of some interest because the pollen record indicates average annual precipitation at about 6750-6000 RCYBP was about 10 cm wetter than today, with predominant spring and summer precipitation and January temperatures about 7° C than today (Hoyt 2000:170-173). Precipitation falls to modern levels by about 5760 RCYBP (Hoyt 2000:Fig. 7.1).

Big Bend and Hueco Mountains, Packrat Middens

Van Devender (1990), speaking of the Chihuahuan Desert as a whole, says,

> The late Wisconsin biotic record reflects strong summer cooling and substantial rainfall with a strong shift to winter sources over the summer monsoon, and does not support the cold-dry paleoclimatic model…. The climate of the early Holocene was transitional between that of the late Wisconsin and more modern regimes later in the Holocene. Winter rainfall continued to be greater than it is today in the Chihuahuan Desert. The southern edge of the winter storm track moved northward in the southern Chihuahuan Desert, resulting in an early (before 9.4 ka) onset of xeric conditions in the Bolson de Mapimi (Van Devender 1990:125-126).

Based on plant appearances and disappearances, Van Devender takes 11,000 RCYBP as the Pleistocene-Holocene boundary, and 9000 RCYBP as the beginning of the Early Holocene. Different taxa enter and depart the record individualistically, making it

difficult to generalize from plants to climate. In the Big Bend, some key Pleistocene taxa (papershell pinyon, juniper, Hinckley oak) disappear at about 9000-11,000 RCYBP (Van Devender 1990:Fig. 7.7), but other characteristically Holocene taxa (sotol, lechuguilla) are present throughout much of the Pleistocene. In Maravillas Canyon, several Holocene taxa (lechuguilla, honey mesquite, crucifixion thorn) make their first major appearance at around 11,000 RCYBP, while several others (blind prickly pear, Mormon tea, Roemer catclaw, creosote bush) make their first major appearance at about 9000 RCYBP (Van Devender 1990:Fig. 7.5). In the Hueco Mountains, a major taxonomic turnover seems to occur at about 8110 RCYBP (Van Devender 1990:Fig. 7.9). Because of elevation differences, even where vegetation shifts can be recognized, they may be out of phase with events in the Coleto Creek catchment.

Salt Basin Pluvial Lakes

The most recent highstand in the series of large pluvial lakes east of El Paso, surrounding Van Horn and Dell City, has a black mat dated at 15,940 ± 320 RCYBP (Wilkins and Currey 1997:Table 1). If there are any more recent black mats of Younger Dryas or Preboreal age, they have not yet been reported.

Paleoenvironmental Sites in the Southwestern US

Carlsbad Cavern, Hidden Cave, Cave #10, Speleothems

Speleothems from these three caves in the New Mexican section of the Guadalupe Mountains provide the best match for the paleoenvironmental history reconstructed at Berger Bluff. Reconstructed moisture history is based on uranium series dating of

speleothem growth (the speleothems in this area grow only during wet intervals). The U-series dates correspond to calendar years, so an approximate concordance was obtained with the CALIB radiocarbon calibration program. Good evidence for growth of speleothems from the second half of the Younger Dryas into the early Holocene was found. Onset of the wet period occurs at 12,425 ± 520 cal BP (equivalent to about 10,505 RCYBP) and the end at 10,613 ± 498 cal BP (very roughly, about 9475 RCYBP). Allowing for the standard error of about ± 500 calendar years, these dates indicate wet conditions throughout most of the span of time represented by the Berger Bluff bench deposits, but ending perhaps a millennium earlier than at Berger Bluff.

Lake Estancia

This large pluvial lake in central New Mexico is one of the most intensively studied in the Southwest. Menking and others (2004) summarize recent modeling studies. The final highstand in this basin has been dated between about 11,500 and 9650 RCYBP, similar to the speleothem findings above, but with onset of the wet period about a millennium earlier (Anderson, Allen and Menking 2002:377). Menking and others estimate that the mean annual temperature was lowered by 5° C and precipitation increased as much as 35-60% above contemporary levels during the Last Glacial Maximum, but no estimates are given for the Younger Dryas.

Rough Canyon, Packrat Middens

Macrofossils indicate precipitation levels 20% above modern and July mean maximum temperatures 3.5-5.0° C below modern. Postglacial warming and drying may have started as early as 12,000 RCYBP and was complete by at least 10,540 RCYBP.

However, there are no samples dated between 10,540 and 7610 RCYBP, so the Preboreal, most of the Boreal, and second half of the Younger Dryas are unrepresented (Betancourt *et al*. 2001).

Winsor Creek Bog B1

This bog in the Sangre de Cristo Mountains northeast of Santa Fe has evidence of circque glaciation at the head of the valley during the Younger Dryas, implying both cooling and an adequate supply of moisture. Four assays on wood and bulk sediment (10,190 ± 60, 10,180 ± 50, 10,070 ± 60 and 9765 ± 55 RCYBP) date a post-Pinedale readavance (Armour, Fawcett and Geissman 2002:725).

Lake Cochise

This pluvial lake in the Willcox Basin of southeastern Arizona has a highstand dated 8900 RCYBP or before, followed by a period of desiccation until the later mid-Holocene (Waters 1989:7).

Stoneman Lake

Sedimentology, macrofossils, pollen and diatoms at this caldera lake in central Arizona indicate cooler temperatures and greater effective temperature before 8500 RCYBP, followed by warmer and drier conditions (Hasbargen 1994).

Montezuma Well

This is a collapsed travertine springmound, also located in central Arizona. Water levels were deeper before 9000 RCYBP; a period of aridity followed at 8700-8400 RCYBP, then intermittently wet conditions at 8400-8200 RCYBP, followed by aridity (Blinn, Hevly and Davis 1994:201).

Dry Lake

Located in the San Bernardino Mountains of southern California, this lake has a continuous series of radiocarbon assays on charcoal extending from near-modern to 8090 ± 40 RCYBP (Bird and Kirby 2006:Table 1). Sediment properties and charcoal content were analyzed and indicate wetter conditions at about 9000-7500 cal BP (approximately 8070-6550 RCYBP), followed by drying.

Paleoenvironmental Sites in Northern Mexico

Lake Palomas Basin

The oldest highstand in Laguna El Fresnal and Laguna Santa Maria is dated at 8269 ± 64 to 8456 ± 97 RCYBP, based on assays of freshwater mussel shell (del ^{13}C corrected, no reservoir correction?). An earlier and higher highstand is undated and is assumed to be Late Pleistocene (Castiglia and Fawcett 2006:113-114).

Laguna Babícora

At this large pluvial lake in Chihuahua, a Younger Dryas-early Holocene wet period is represented by radiocarbon assays of 10,976 ± 115 RCYBP and 9614 ± 130 RCYBP on humic material from lake sediments (Ortega-Ramírez et al. 1998:Table 2), followed by increasing aridification until about 6000 RCYBP. The sediments indicate a shallow perennial lake and/or bog.

Alta Babícora

A deep, freshwater lake existed here during the late Pleistocene, and wet conditions continued into the early Holocene (Metcalfe *et al*. 2002:99). Unfortunately the period bracketing the Pleistocene/Holocene transition is poorly dated. A single assay 0f 9500 ± 930 RCYBP on bulk sediment is reported (Metcalfe *et al*. 2002:Table 1).

Lake Chapala

This large pluvial lake is located in the northern third of the Baja California Peninsula. A large lake filled the basin sometime before 9070 ± 60 RCYBP (charcoal), and falling lake levels thereafter ended in desiccation by about 7450 RCYBP (Davis 2003).

Paleoenvironmental Sites in Other Regions

The paleoenvironmental literature from the Great Basin is too voluminous to summarize here, but some of the pluvial lakes there also show wet conditions in the Younger Dryas (Oviatt *et al*. 2005) and early Holocene, while others do not. The Lake

Bonneville basin was wet from before 13,000 to 8800 RCYBP (Oviatt, Madsen and Schmitt 2003). Lake Lahontan experienced a Younger Dryas highstand between 10,850 and 9600 RCYBP (Benson, Kashgarian and Rubin 1995:24). In southern Nevada, organic black mats and spring runs appear at 11,600 RCYBP, with spring activity peaking at 11,000-9500 RCYBP, followed by desiccation of most springs by 9500-7000 RCYBP (Quade, Forester and Whelan 2003).

UNANSWERED QUESTIONS

Why Is the Bench Not a Calcareous Fen?

Fens are groundwater-supported wetlands (for examples, see Amon *et al*. 2002; Miner and Ketterling 2003). They are often alkaline, unlike *bogs*, which are fed by vadose water (precipitation and runoff) and are usually acid. Fens often have surface peat layers, sometimes with over 90% organic matter (Moorhead, Moynihan and Simpson 2000:362). According to Bedford and Godwin (2003:612), "Fens receiving high flows of calcium-rich water are called calcareous fens and support a distinct flora of plant species called calcicoles because of their affinity for calcium-rich sites." The bench deposits at Berger Bluff have many of the characteristics of a calcareous fen: abundant base-rich groundwater, carbonate deposits, slow internal drainage, high species diversity of diatoms and snails, and possibly even calcicole flora (the plants contributing the abundant rhizoconcretions have not been identified, but perhaps they were calcicole species). Indeed, both the density and species richness of snails in the bench deposits are probably owing to its resemblance to a calcareous fen. And yet there are no peat deposits, no gyttja, and no black mats in the deposits. There are dark bands in the cutbank that superficially resemble the Younger Dryas-aged black mats of the Southwest and Great

Basin, but closer inspection shows these are fine-grained silt and clay strata, not organic zones. Processing of sediment samples for humin assays showed that while inorganic carbon content is high, organic carbon content in the bench sediments is very low. So why is there no peat at Berger Bluff? Why does Berger Bluff not look like the Aubrey site? I can only guess that topography must have been the critical factor. There were no closed depressions at Berger Bluff, although there must have been many closed depressions elsewhere on the floodplain at the time. Because there was no closed depression, saturation was never maintained long enough to allow peat formation. Another possibility is that the climate, although weakly seasonal, allowed the floodplain sediments to dry out at times.

This problem highlights the importance of understanding topography when doing geoarcheological interpretation. Topography is hard to judge when deeply buried sites can only be examined in a cutbank, test pits, or a few backhoe trenches. The bench project could have benefited greatly from some remote sensing surveys on the north side of the creek.

How Does Autocyclic Bedding Develop in a Narrow Creek Valley?

In Chapter 4, I asked whether the cyclic bedding seen in the bench is allocyclic or autocyclic in nature, and proposed that one test might be to look for stratigraphic variations in biota that matched the muddy-sandy character of the couplets. Applying these tests to diatoms and snails, biotic variation appears to be mostly long-term rather than cyclic in nature. If bedding is autocyclic, then, how could Coleto Creek shift far enough away from the site to create fine-grained floodbasin deposits? The valley is rather narrow here. Here is another area of inquiry that could have been illuminated by remote

sensing. Remote sensing was not included in the original budget or the scope of work, and I do not know if permission could have been obtained to investigate deposits on the opposite side of the creek.

How Representative Are the Bench Deposits?

The northern side of the Berger Bluff site was removed long ago by erosion from Coleto Creek. But how much has been lost? Is it possible that what is preserved is really just the outskirts of a denser archeological deposit, now vanished? If these deposits had never been lost, would the early occupations look more like a base camp and less like a diurnal way station?

Why Are There So Many Inversions Among the Radiocarbon Assays?

Many of the radiocarbon assays from the bench are in inverted stratigraphic relationships, highlighting the difficulty in securing representative assays for very old sites in alluvial context with a history of active groundwater. My assessment of bioturbation in the bench deposits has always been that it was limited, but it is possible I have underestimated the extent of bioturbation. Where there are features in place (such as the microvertebrate bone bed, or an *in situ* chipping area discovered near the too of unit N109 E103), they seem to show little evidence of disruption.

PROCEDURAL FINDINGS

In addition to the substantive findings that have been summarized above, a few things have been learned along the way that relate to the practice of paleoenvironmental studies.

The Importance of Rare Species

For most archeologists, the greater the frequency of an object, the greater its importance. A site with ten thousand pieces of chipping debris usually gets more attention than a site with five flakes. This leads to the inevitable conflation of frequency with significance. I would argue that it is often the rarest items that carry the highest information payload, and this is never more true than when dealing with biological proxy data.

A corollary is that when a species is common, archeologists may fall into the trap of thinking commonness implies optimum environmental conditions. In many cases, the opposite is true. Many organisms produce large numbers of offspring specifically because the environment is hostile and few are likely to survive to adulthood (see Vermeij and Herbert 2004). Species like these, usually with high fecundity and short lifespans, are referred to as "weedy" species, and some examples might be the snails *Oligyra orbiculata* (medium-bodied) and *Helicodiscus singleyanus* (a microsnail) or the soil diatom *Hantzschia amphioxys*. These tend to occur in large numbers and be ubiquitous. If these species are, in fact, adapted to stressful environments, their presence may carry some useful information for habitat reconstruction, but their propensity for ubiquity often makes it hard to detect trends.

Among some of the characteristics of rare species addressed by Gaston and Kunin (1997:22) are the following; rare species tend to

- have lower reproductive investment

- have poorer dispersal abilities
- use less common resources and/or a narrower range of resources
- be likely to occupy a higher trophic level

I would argue that rare species may often carry some of the highest paleoenvironmental information payload. Examples are the snails *Valvata tricarinata* and *Pomatiopsis lapidaria*, the freshwater mussel *Megalonaias nervosa*, and the extinct tortoise *Gopherus hexagonatus*. In using correspondence analysis to examine the diatom data, I found it necessary to simply delete some of the most abundant and cosmopolitan species from the database, and it was only after these species were eliminated that useful numerical analysis could proceed.

Archeology first emerged as a discipline from a fascination with the curious, the odd, and the unique, and has since evolved, at times, into an obsession with the commonplace and the abundant. I argue we must always ask why things are common, especially when dealing with biological proxy data.

The Usefulness of Numerical Analysis

In this study, numerical analysis was applied to grain-size data, diatoms, and snails, the things that could suitably be quantified. In all three domains, numerical analysis succeeded in extracting trends and relationships that were never apparent from simple inspection. When looking at the cutbank or the unit profiles, the depositional strata I have defined for the site often appear obscure and nearly invisible. Contacts between the units are extremely gradational, and the units themselves do not differ much visually. Nevertheless, numerical analysis has demonstrated that each stratum has a

unique grain-size signature, a unique diatom signature, and a unique snail signature (Fig. 11.2). Furthermore, there is a long-term signature of regional drying during the Younger Dryas and early Holocene that crosscuts all the strata. A long-term trend toward upsection coarsening of the sediments and upsection changes in mesic-adapted by xeric-adapted diatoms and snails is discernible only through numerical analysis.

The lesson to be learned is that even when stratigraphy is subtle (and, perhaps in some cases bioturbated), careful study and numerical analysis may be able to extract paleoenvironmental history from seemingly intractable dirt.

A Geologic Model for Finding the Next Berger Bluff

The bench deposits are exceptional in their preservation of bone, shell, diatoms, freshwater sponge spicules, phytoliths, and chrysophyte cysts. This degree of preservation seems to have resulted because the bench deposits are a carbonate island in a sea of potentially acidic Miocene sand, and the carbonate has partly buffered the effects of groundwater and acidity that might result from trace amounts of iron or sulfur. There are, however, other localities where remnant down-dip outcrops of Goliad Formation bedrock emerge from younger deposits. Some of these are large enough to appear on the Geologic Atlas of Texas. One of these occurs downstream on Coleto Creek near Raisin, and there are probably others. If sites like this can be located, they may prove to be comparable archives for proxy paleoenvironmental data.

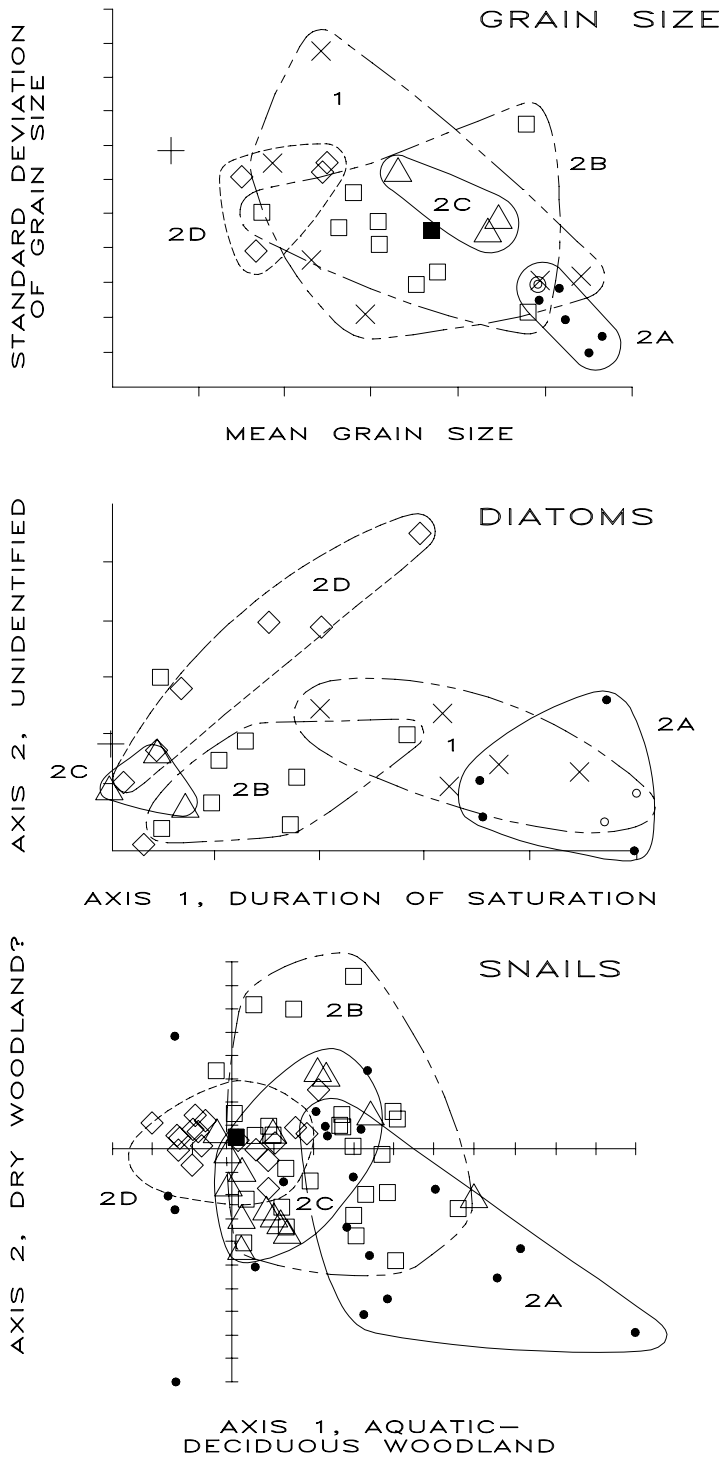

Figure 11.2. Numerical Analysis Yields Stratigraphic Signatures. Simplified versions of Figs. 4.68, 7.12, and 8.81 with axis scaling omitted.

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Appendix 1: Laboratory and Numerical Methods of Sediment Analysis

LAB TECHNIQUES FOR GRAIN-SIZE ANALYSIS OF SEDIMENTS

The lab techniques employed for grain size analysis of the bench sediments were, for the most part, the standard methods advocated by Folk (1980), employing dry sieving for gravel and sand-sized fractions and pipette analysis of the fines (based on Stoke's Law of settling velocity). However, the partially cemented nature of the sediments posed some special difficulties, as did persistent sample loss during blender homogenization of the fines. Some correction factors were introduced to try to counter these problems, and these are discussed below. Laboratory methods for analysis of organic carbon content are discussed elsewhere by Michael Marchbanks.

Because the sediments were partially cemented, they contain many carbonate aggregates. These range in size from the large masses and tubular rhizoconcretions discussed elsewhere in this report to small, irregular aggregates a millimeter or so across. These latter were especially abundant and troublesome in the grain-size samples. Ultimately, I devoted about four months to disaggregating and analyzing a series of samples with what I considered to be acceptable precision. Sediment samples for grain-size analysis were removed from bulk matrix sample bags and therefore come from the lower three centimeters of each five-centimeter level, in contrast to the organic carbon samples, which were extracted from the pollen/phytolith samples and therefore come from the one or two centimeters of fill above that; otherwise, the samples are comparable. Grain-size samples were generally about 15 g of dry sediment. Two separate data forms were used: a master data form to track various weights as well as the weights of pipette

grades, and a separate form for dry sieving of the coarse fractions. Lab methods were as follows:

1. About 15 g of dry sediment was extracted; snail shells, chert flakes, charcoal, or other contaminants were picked out; the remaining sample was weighed on a triple beam balance and the weight was recorded;
2. The sample was gently crushed with a rubber stopper (to avoid breaking sediment grains);
3. The sample was placed in a sealed jar with dispersant solution and shaken for a while, then allowed to stand from one to several days.
4. The settled sample was reshaken, then immediately washed with a squeeze bottle of dispersant solution into a #230 sieve held over a 500 ml beaker; the coarse fraction retained on the screen was then washed into another beaker with distilled water;
5. The pyrex beaker with coarse fraction was baked in an oven to drive off the water, then allowed to cool to room temperature;
6. After adjusting to room temperature and humidity (which might take several days) the coarse fraction was weighed, in the beaker, on an analytical balance and the weight recorded;
7. The dry coarse fraction was saturated in 25% HCl until effervescence ceased (i.e., long enough to disaggregate small diagenetically-cemented carbonate masses, but not long enough to digest significantly any sand-sized carbonate clasts that might have been present). The sample was then diluted and neutralized so that residual acid would not alter the mesh size when the sample was rinsed on the #230 sieve;
8. The carbonate-free coarse fraction was rinsed with distilled water into a Pyrex beaker and again baked to drive off water; after adjustment to room conditions, the sample was weighed as before;
9. The difference in weights before and after the acid bath was taken as an approximation of the carbonate loss from the coarse fraction. Actually, some fines are also liberated as well by digestion of the carbonate masses, but these cannot practically be recovered or measured because of acid contamination; this is simply taken as unavoidable error;
10. The carbonate-free coarse sediment was then sieved in nested, hand-tapped screens for 30 minutes;
11. After sieving, some sediment passing the #230 sieve would inevitably be present; this fraction was considered to be sufficiently acid-free to add to the beaker with the fines;
12. The coarse grade on each screen was collected and weighed separately and recorded;
13. Fines from the 500 ml beaker were washed with dispersant into a blender and homogenized at high speed for 5 minute. Invariably some sample loss occurred in this step, which had to be corrected mathematically as described below;
14. The blender contents were washed with enough dispersant into a labeled 1 liter graduated cylinder to fill it exactly to the 1 liter mark; the cylinder was then allowed to stand overnight;
15. Eleven 50 ml beakers were marked and preweighed to correspond to each cylinder;
16. The suspension in the graduated cylinder was stirred and then exactly 20 ml of suspension for each beaker was withdrawn by pipette, as described by Folk, at timed

intervals; when samples were occasionally missed, the sample was restirred and the series repeated;

17. Samples were oven-dried, then allowed to adjust to ambient temperature and humidity (this last factor proved to be critical), then weighed on an analytical balance. In practice it proved advisable to let the samples stand uncovered in the balance room for about three days before weighing;
18. Sample weights for the fines were checked for monotonically declining weights; where violations were found, the series was repeated provided enough suspension remained; if not, the entire sample procedure was repeated beginning at step 1.

Individual sieve fractions in the coarse grades were saved in labeled vials in case any future microscopic studies should be contemplated. Baked mud samples, however, were discarded.

COMPUTATIONAL TECHNIQUES AND SOURCES OF ERROR

Two main sources of potential error were encountered in the lab work. The first is possible differential digestion of carbonate masses. The cessation of effervescence was used as a timing standard, the assumption being that the carbonate in the sediment had nearly neutralized the acid. Related to this problem is the fact that some fines are inevitably trapped by the carbonate aggregates and are lost to the analysis when the sample is rinsed. Since the acid goes with the lost fines, the difficulty of recovery was considered to be too troublesome to justify the small increase in precision expected. Carbonate loss from the coarse fraction was measured as a variable of interest in its own right, and was also used as a correction factor to recompute the coarse grades, as described below.

The other chief source of error lay in sample loss during blending. Eventually the course of action chosen was to assume that enough homogenization occurred before sample loss to justify treating the remainder as representative of the original sample.

Enough sample weight was then added back in mathematically (using the cumulative weight in the first pipette sample withdrawn as an estimator). The original weight of sediment passing the #230 sieve was divided by the cumulative weight in the first pipette grade to arrive at a correction factor for blender loss.

The final table of raw grade weights was keypunched in 1980 and used as input for an SPSS program which simultaneously applied the correction factors mentioned as recomputed the grade weights as percentages of the raw sample, so that sample-to-sample variations in amount would not matter. This was done on the mainframe computer at the Computation Center, University of Texas at Austin, but could as easily have been done with a personal computer and spreadsheet program had such things been available in 1980. In 1986, the corrected data table was entered in a Lotus 1-2-3 worksheet in order to produce the tables for this report.

The formulae used to produce the corrected data table are as follows:

1. [weight of raw sample] - [wt. of coarse fraction before acid]

2. $\frac{\text{wt. of fines}}{\text{cumulative wt. in pipette grade 1}}$ = correction factor for blender loss

3. [wt. in each pipette grade] X [blender correction factor] = corrected pipette weights

4. [weight of raw sample] - [weight loss after acid] = sample weight minus carbonate

5. SAND GRADE PERCENTAGE = $\frac{\text{sand grade}}{\text{sample weight minus carbonate}}$

6. SILT/CLAY GRADE PERCENTAGE = $\frac{\text{corrected pipette weight}}{\text{sample weight minus carbonate}}$

PHI TRANSFORMATION OF THE WENTWORTH GRADE SCALE

Measures of grain size used in this report are based on the phi (Φ) transformation of the Wentworth metric grade scale. In the Wentworth scale each size grade is half the size of the next coarser grade; for example, coarse sand falls in the range 1.0 to 0.5 mm in diameter while very coarse sand is 2.0 to 1.0 mm in diameter. This scale is well-suited to natural frequency distributions of particle sizes, which tend to be exponentially scaled and to approximate a log-normal distribution. The derivation of the phi scale is given by Krumbein (1978; original 1936) and is defined as

$$\Phi = -\log_2 X$$

where X is the grade limit in millimeters. This study uses grades measured at 0.5 phi intervals. A concordance of the Wentworth and phi grades is given in Table 4.1.

NUMERICAL METHODS

Three statistics were computed for the grain size data. The *mean grain size* (M Φ, the *phi arithmetic mean*) was used as a measure of central tendency, and the *standard deviation* (sigma Φ) was used as a measure of dispersion or sorting. The standard deviation (or more properly, the *coefficient of variation*, CV) is, of course, inversely proportional to the degree of sorting (heterogeneous, poorly sorted sediments have large coefficients of variation).

The computational method is essentially that of Folk (1980), which in turn is closely similar to and based on the "method of moments" as advocated by Krumbein (1978). The procedure is the same as that termed *computation of the mean from grouped*

data by Blalock (1972:61 ff). This differs from more customary computational methods in that it yields the *average grade in phi units* of a sample rather than the *average quantity of sediment in a grade*, which would be of little interest.

The principal differences between the computational method of Folk and that used here are that

1) the data used are percent in grade drawn from the data table corrected for carbonate loss and blender loss (Table ___) rather than weight in grade. The percentages do not add up to 100% as in Krumbein's (1978:Table II) example since varying amounts of the sample are comprised of clay grades finer than 9.0 phi for which we have no data.

2) the mean and standard deviation are only computed for grades up to 9.0 phi (i.e., coarser than .002 mm). No arbitrary "pan fraction" figure is used as was employed by Folk (1980). The statistics computed here are, then, s, simply measures of that portion of the sample for which we have grade-by-grade data.

The mean grain size is given as

$$M\,\Phi = \frac{\Sigma\,(f\,d)}{\Sigma\,(f)}$$

where $M\,\Phi$ = mean grain size in phi units
Σ = the sum of
f = the weight percent of sediment in a grade
d = the midpoint of a grade interval

The standard deviation is given as

$$\Sigma\,\Phi = SQR\left[\ \frac{\Sigma\,[f(M\,\Phi)^2]}{\Sigma(f)}\ \right]$$

where $\Sigma\,\Phi$ = standard deviation in phi units
SQR = square root

The coefficient is given as

$$CV = \Sigma \Phi / M \Phi$$

and is a dimensionless ratio in which the standard deviation is standardized by the mean, so as to yield a measure of sorting which is not biased by the average grain size of the sample.

Besides Krumbein (1978) and Folk (1980), the reader may wish to consult McManus (1982) and Pierce and Graus (1981) on use of the phi scale and derivative statistics.

Grain size statistics for samples discussed in this report were originally calculated by hand in 1983, using a pocket calculator. In 1986 all the statistics were recalculated on an IBM PC with a BASIC program (GRAIN) written specifically for this purpose. A listing of the program is on file at the Center for Archaeological Research. Statistics presented in this report are those calculated with the BASIC program.

Table A1.1 (following) lists the grain-size data for the bench and Lissie terrace samples. The first 28 samples represent the composite grain-size column (three samples from N109 E103, the remaining 25 from N110 E102). There are also two miscellaneous samples from N109 E96, and a single sample from stratum 2E in the cutbank with all grades analyzed (a second sample from stratum 2E was also analyzed, but only for gravel and sand; it is not listed here).

Table A1.1: Grain-Size Data for Bench and Lissie Terrace Samples.

	Gravel1 -2.5 to -2.0 Φ	Gravel2 -2.0 to -1.5 Φ	Gravel3 -1.5 to -1.0 Φ	Sand 1 -1.0 to -0.5 Φ	Sand 2 -0.5 to 0.0 Φ	Sand 3 0.0 to 0.5 Φ	Sand 4 0.5 to 1.0 Φ	Sand 5 1.0 to 1.5 Φ
N109 E103								
93.14-92.90	0	0	0.0008	0.0004	0.0038	0.0096	0.0283	0.0206
92.90-92.85	0	0	0.0024	0.0036	0.0073	0.0183	0.0544	0.0392
92.85-92.80	0	0	0	0.0033	0.0079	0.0173	0.0574	0.0431
N110 E102								
92.80-92.75	0.0101	0	0.0037	0.0037	0.0093	0.0228	0.0641	0.0494
92.75-92.70	0	0	0.0018	0.0018	0.008	0.0156	0.0529	0.0417
92.70-92.65	0	0.007	0	0.0031	0.0034	0.0087	0.0301	0.0249
92.65-92.60	0	0	0	0.0006	0.002	0.0061	0.0182	0.0148
92.60-92.55	0	0	0	0.0006	0.0021	0.0074	0.0177	0.0141
92.55-92.50	0	0	0	0.0017	0.0077	0.0109	0.0262	0.0184
92.50-92.45	0	0	0.0009	0.0039	0.0051	0.0131	0.0344	0.0212
92.45-92.40	0	0	0.0007	0.0042	0.0056	0.0158	0.0439	0.0263
92.40-92.35	0	0	0	0.0034	0.0069	0.0149	0.0366	0.0265
92.35-92.30	0	0	0	0.0029	0.0064	0.0116	0.0264	0.0173
92.30-92.25	0	0	0	0	0.0017	0.0037	0.0124	0.0128
92.25-92.20	0	0	0	0	0.0006	0.0043	0.0132	0.0129
92.20-92.15	0	0	0.0006	0.0003	0.0001	0.0011	0.0048	0.0054
92.15-92.10	0	0	0	0	0.0003	0.0006	0.0027	0.0028
92.10-92.05	0	0	0	0.0008	0.0009	0.0008	0.0031	0.0031
92.05-92.00	0	0	0	0.0103	0.0003	0.0011	0.005	0.0043
92.00-91.95	0	0	0	0	0.0008	0.0005	0.004	0.0052
91.95-91.90	0	0	0	0	0	0.0001	0.0011	0.0031
91.90-91.85	0	0	0	0.0008	0	0.0018	0.0048	0.006
91.85-91.80	0	0	0	0.0007	0.0005	0.0009	0.0021	0.0017
91.80-91.75	0	0	0	0.0029	0.0003	0.0014	0.0056	0.005
91.75-91.70	0.0273	0.0135	0.0044	0.0132	0.0137	0.0154	0.031	0.0215
91.70-91.65	0.014	0	0.0105	0.0106	0.0127	0.0211	0.0399	0.0285
91.65-91.60	0	0	0.0011	0.0064	0.0072	0.0151	0.0343	0.0259
91.60-91.55	0	0	0	0.0004	0.001	0.0052	0.0138	0.0136
N109 E96								
92.30-92.25	0	0.0057	0.0008	0.0065	0.0056	0.0175	0.0535	0.0447
92.15-92.10	0	0	0.0003	0.0012	0.0012	0.0021	0.0076	0.0033
Cutbank								
93.40-93.35	0.0212	0.004	0.0058	0.0101	0.0199	0.0364	0.079	0.05
Lissie terrace								
Lissie 2-1	0.0223	0.0115	0.0035	0.0098	0.0208	0.0286	0.0602	0.0501
Lissie 1-2	0	0	0	0	0	0.0001	0.0008	0.0038
Lissie 1-3	0	0	0	0.0004	0	0.0001	0.0035	0.0123

(Table A1.1, continued)

	Sand 6 1.5 to 2.0 Φ	Sand 7 2.0 to 2.5 Φ	Sand 8 2.5 to 3.0 Φ	Sand 9 3.0 to 3.5 Φ	Sand 10 3.5 to 4.0 Φ	Silt 1 4.0 to 4.5 Φ	Silt 2 4.5 to 5.0 Φ	Silt 3 5.0 to 5.5 Φ
N109 E103								
93.14-92.90	0.041	0.0305	0.0672	0.0791	0.0701	0.0613	0.0617	0.0388
92.90-92.85	0.0764	0.053	0.097	0.0717	0.0429	0.0286	0.0366	0.0321
92.85-92.80	0.0876	0.0592	0.1008	0.0694	0.0384	0.0288	0.0316	0.0389
N110 E102								
92.80-92.75	0.1063	0.0738	0.1177	0.0732	0.0363	0.0322	0.0342	0.0299
92.75-92.70	0.093	0.0693	0.1254	0.0845	0.0409	0.0243	0.0382	0.0243
92.70-92.65	0.0575	0.0451	0.0876	0.0717	0.048	0.0343	0.047	0.0394
92.65-92.60	0.0361	0.0329	0.0678	0.0622	0.045	0.0442	0.0542	0.0432
92.60-92.55	0.0342	0.0309	0.0667	0.0589	0.0274	0.028	0.1154	0.0175
92.55-92.50	0.0454	0.0399	0.0845	0.0659	0.0391	0.0438	0.0435	0.0431
92.50-92.45	0.0573	0.049	0.0921	0.0763	0.0353	0.038	0.059	0.0498
92.45-92.40	0.0707	0.0579	0.0983	0.0749	0.0282	0.0375	0.0504	0.0448
92.40-92.35	0.0701	0.0647	0.1163	0.0768	0.033	0.065	0.0422	0.0364
92.35-92.30	0.0459	0.048	0.1123	0.098	0.0396	0.0636	0.0473	0.039
92.30-92.25	0.0477	0.0502	0.0979	0.0784	0.044	0.0477	0.0588	0.0521
92.25-92.20	0.0476	0.0504	0.1058	0.0811	0.044	0.0498	0.0728	0.03
92.20-92.15	0.0229	0.0255	0.0644	0.0442	0.042	0.0545	0.0733	0.0398
92.15-92.10	0.0091	0.0118	0.0435	0.0551	0.038	0.0549	0.0905	0.0426
92.10-92.05	0.0084	0.0102	0.0384	0.0538	0.0413	0.0563	0.0815	0.0461
92.05-92.00	0.0119	0.0139	0.0451	0.0564	0.0416	0.0591	0.0781	0.0447
92.00-91.95	0.0202	0.02	0.0526	0.0559	0.0441	0.0555	0.0737	0.0473
91.95-91.90	0.0136	0.0162	0.0471	0.0584	0.0435	0.0545	0.0657	0.0482
91.90-91.85	0.0356	0.0265	0.0616	0.0614	0.038	0.0406	0.0601	0.0555
91.85-91.80	0.0145	0.0226	0.07	0.0679	0.0443	0.0524	0.0681	0.0454
91.80-91.75	0.0209	0.0227	0.0672	0.0699	0.0439	0.0377	0.0553	0.0519
91.75-91.70	0.0447	0.0394	0.0851	0.0664	0.0345	0.0355	0.0526	0.0411
91.70-91.65	0.061	0.0597	0.1298	0.0864	0.0403	0.0338	0.0435	0.0242
91.65-91.60	0.0607	0.0621	0.1473	0.099	0.0483	0.0255	0.0426	0.0378
91.60-91.55	0.0451	0.0635	0.1621	0.1177	0.0541	0.0363	0.0431	0.0323
N109 E96								
92.30-92.25	0.1008	0.0757	0.1185	0.0693	0.033	0.0152	0.0444	0.022
92.15-92.10	0.0118	0.0186	0.0719	0.0794	0.0391	0.0545	0.0632	0.0659
Cutbank								
93.40-93.35	0.1018	0.075	0.1292	0.1023	0.04	0.0106	0.0216	0.029
Lissie terrace								
Lissie 2-1	0.1136	0.0876	0.1347	0.077	0.0387	0.0238	0.0368	0.015
Lissie 1-2	0.0515	0.1008	0.2072	0.1243	0.0452	0.0498	0.0579	0.0279
Lissie 1-3	0.1211	0.1986	0.325	0.1272	0.044	0.018	0.0192	0.0114

(Table A1.1, continued)

	Silt 4 5.5 to 6.0 Φ	Silt 5 6.0 to 6.5 Φ	Silt 6 6.5 to 7.0 Φ	Silt 7 7.0 to 7.5 Φ	Silt 8 7.5 8.0 Φ	Clay 1 8.0 to 8.5 Φ	Clay 2 8.5 to 9.0 Φ
N109 E103							
93.14-92.90	0.0373	0.0266	0.0347	0.0325	0.0358	0.0306	0.0129
92.90-92.85	0.0341	0.0303	0.0327	0.0251	0.0314	0.0307	0.0063
92.85-92.80	0.0291	0.034	0.0249	0.0393	0.0277	0.0375	0.0077
N110 E102							
92.80-92.75	0.0279	0.02	0.0213	0.0207	0.019	0.0131	0.0243
92.75-92.70	0.0208	0.0243	0.0278	0.0139	0.0139	0.0139	0.0139
92.70-92.65	0.0405	0.0379	0.0332	0.0296	0.0257	0.0289	0.022
92.65-92.60	0.048	0.0507	0.0405	0.0346	0.035	0.0333	0.0254
92.60-92.55	0.042	0.042	0.0455	0.0385	0.028	0.0245	0.0213
92.55-92.50	0.0438	0.0418	0.0418	0.0339	0.0277	0.0309	0.0741
92.50-92.45	0.0425	0.0323	0.0184	0.0514	0.0228	0.0162	0.0108
92.45-92.40	0.0375	0.0348	0.0282	0.0302	0.0252	0.0209	0.0176
92.40-92.35	0.0375	0.0304	0.03	0.0264	0.015	0.015	0.0232
92.35-92.30	0.0343	0.0336	0.0314	0.0264	0.0188	0.0195	0.0209
92.30-92.25	0.0424	0.041	0.0372	0.0287	0.0261	0.0205	0.0182
92.25-92.20	0.0383	0.0401	0.0338	0.0254	0.0244	0.0167	0.0172
92.20-92.15	0.0523	0.0471	0.0387	0.0379	0.0261	0.0258	0.0147
92.15-92.10	0.0542	0.0546	0.0549	0.031	0.0366	0.0225	0.0384
92.10-92.05	0.0555	0.0551	0.0508	0.0394	0.0291	0.0252	0.0224
92.05-92.00	0.0531	0.0584	0.0418	0.0323	0.038	0.0239	0.0236
92.00-91.95	0.0693	0.0456	0.0517	0.0379	0.0368	0.0297	0.0203
91.95-91.90	0.059	0.0536	0.0536	0.0424	0.0375	0.0322	0.0259
91.90-91.85	0.0575	0.0514	0.0452	0.0401	0.039	0.0267	0.0185
91.85-91.80	0.0555	0.0511	0.0397	0.0362	0.0314	0.0354	0.0511
91.80-91.75	0.0549	0.0463	0.0433	0.0437	0.0283	0.03	0.0227
91.75-91.70	0.0414	0.0463	0.0325	0.0329	0.025	0.0228	0.0116
91.70-91.65	0.0381	0.0303	0.0274	0.0242	0.0214	0.0132	0.0125
91.65-91.60	0.035	0.0306	0.0318	0.0199	0.0195	0.0127	0.0107
91.60-91.55	0.037	0.028	0.0305	0.0237	0.0345	0.0108	0.0093
N109 E96							
92.30-92.25	0.0353	0.0326	0.0326	0.0231	0.0129	0.0102	0.0144
92.15-92.10	0.0571	0.0457	0.0378	0.0395	0.0264	0.0224	0.0321
Cutbank							
93.40-93.35	0.0193	0.0147	0.0161	0.0106	0.0115	0.0083	0.0382
Lissie terrace							
Lissie 2-1	0.0163	0.0064	0.0083	0.0111	0.0066	0.0186	0.0155
Lissie 1-2	0.0314	0.0311	0.0341	0.0287	0.0219	0.0168	0.01
Lissie 1-3	0.0119	0.0069	0.0057	0.0123	0	0.0082	0

(Table A1.1, continued)

	Gravel total	Sand total	Silt total	Clay + analytical error
N109 E103				
93.14-92.90	0.0008	0.0627	0	0.9365
92.90-92.85	0.0024	0.1228	0	0.8748
92.85-92.80	0	0.129	0	0.871
N110 E102				
92.80-92.75	0.0138	0.1493	0	0.8369
92.75-92.70	0.0018	0.12	0	0.8782
92.70-92.65	0.007	0.0702	0	0.9228
92.65-92.60	0	0.0417	0	0.9583
92.60-92.55	0	0.0419	0	0.9581
92.55-92.50	0	0.0649	0	0.9351
92.50-92.45	0.0009	0.0777	0	0.9214
92.45-92.40	0.0007	0.0958	0	0.9035
92.40-92.35	0	0.0883	0	0.9117
92.35-92.30	0	0.0646	0	0.9354
92.30-92.25	0	0.0306	0	0.9694
92.25-92.20	0	0.031	0	0.969
92.20-92.15	0.0006	0.0117	0	0.9877
92.15-92.10	0	0.0064	0	0.9936
92.10-92.05	0	0.0087	0	0.9913
92.05-92.00	0	0.021	0	0.979
92.00-91.95	0	0.0105	0	0.9895
91.95-91.90	0	0.0043	0	0.9957
91.90-91.85	0	0.0134	0	0.9866
91.85-91.80	0	0.0059	0	0.9941
91.80-91.75	0	0.0152	0	0.9848
91.75-91.70	0.0452	0.0948	0	0.86
91.70-91.65	0.0245	0.1128	0	0.8627
91.65-91.60	0.0011	0.0889	0	0.91
91.60-91.55	0	0.034	0	0.966
N109 E96				
92.30-92.25	0.0065	0.1278	0	0.8657
92.15-92.10	0.0003	0.0154	0	0.9843
Cutbank				
93.40-93.35	0.031	0.1954	0	0.7736
Lissie terrace				
Lissie 2-1	0.0373	0.1695	0	0.7932
Lissie 1-2	0	0.0047	0	0.9953
Lissie 1-3	0	0.0163	0	0.9837

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Appendix 2: Laboratory Procedure for Determining Organic and Carbonate Content of Sediment Samples

MICHAEL MARCHBANKS

SAMPLES SELECTED FOR ANALYSIS

Small sediment samples extracted from the phytolith/pollen sample columns in N109 E103 and N110 E102 were used for this analysis. These were selected so as to duplicate as nearly as possible the grain-size samples extracted from the matrix samples. However, two samples at 91.85-91.80 m and 91.80-91.75 were unavailable for analysis, and duplicate samples at the top of the column were unavailable for three levels, so three samples at slightly different elevations were substituted. Except for these differences, the grain-size and organic carbon/carbonate sample columns are comparable.

SAMPLE PREPARATION

Step 1: Visible rocks, snail shell fragments, and organic matter (roots and leaves) were removed from the sediment sample.

Step 2: The sample was ground in a clean mortar and pestle and sifted through a 100 mesh screen. The ground sample was stored in a clean, labeled glass bottle.

EXPERIMENTAL PROCEDURE

Step 1: Initial weight. A single sheet of #42 filter paper was weighed on the analytical balance and approximately one gram (1.0 g) of the sample was placed on it. Combined weight of the paper and sample was determined.

Step 2: Carbonate removal. Approximately ten milliliters (10 ml) of one normal (1N) HCl was added to the sample to remove carbonates. The HCl passed through the filter paper and four five-milliliter rinses of distilled water were administered to remove residual HCl.

Step 3: The sample was dried and left in a desiccator to cool to room temperature.

Step 4: A clean crucible was weighed. The sample was then transferred, with a camel hair brush, into the crucible and the combined weight of the crucible and sample was determined.

Step 5: Ashing. The soil sample was heated in a furnace at about 850° C for 1.5 hours to burn out the finely divided organic matter. Samples were then placed in the desiccator to cool.

Step 6: Final weight. Final weight of the ashed sample was determined by weighing the cooled crucible and sample and subtracting the crucible weight. Color of the ashed sample was also recorded.

COMPUTATION AND REPLICABILITY

Three subsamples were run from each sample so that the results could be averaged. In a few cases, some subsamples were ruined by laboratory mishaps so that fewer than three subsamples were available. A computer program, termed ORG.BAS, was written in BASIC to compute organic percentages from keyboard data entry, printing both subsample percentages and averaged subsample percentages. In some cases a slight film of sediment residue could not be removed from the filter paper, so a correction factor (based on the difference between the clean and dirty paper weights) was built into the program. The organic carbon content was initially computed as the weight loss after ashing divided by the initial sample weight before acid treatment, but this method of computation produced organic and carbonate curves with nearly perfect inverse correlation. This should not be true, since carbonate entry is believed to be postdepositional (diagenetic) and should be unrelated to original organic content of the sediment. The program was later written so as to divide the weight loss after ashing by the acid-rinsed, carbonate-free weight.

Appendix 3: Magnetic Susceptibility Samples

ORIGIN OF THE SAMPLES

A total of 127 magnetic susceptibility samples was analyzed (Table A3.1). Ten of these are from the upper deposits (strata 4 and 5) and the remaining 117 are from the bench deposits. The 10 samples from the upper deposits (numbers 100-109) were extracted from a series of sediment samples collected on April 17, 1981, by K. Brown and J. DeCosta from the west wall of the abandoned blufftop excavation block, near the southwest (N97 E96) corner. The original samples were about 2 cm or more thick, and of variable width and depth. Magnetic susceptibility samples 100 and 109 correspond to diatom samples 29 and 39, respectively.

With few exceptions, the samples from the bench sediments were extracted from pollen\phytolith ("phytopol") samples, and therefore derive from the upper 2 cm of a 5 cm excavation level. Sample 42 came from a "phytopol" sample, but was extracted from excess sediment returned by Rick Holloway after processing for pollen analysis. Sample 51 was extracted from a matrix sample ("CVS" sample) and therefore probably derives from the lower 3 cm of the 92.70-92.65 m level. Samples 110 and 143A are from feature fill. Samples 111, 145, 145A, 147A, 147B, 149A, and 149B are from special sediment samples collected to investigate depositional units encountered in excavation. Samples 112-115 were extracted from bulk sediment samples of sand and gravel that were collected (chiefly for grain-size analysis) from the cutbank exposure of stratum 2E. The location is shown on Fig. 3.1 ("Stratum 2E sediment sample").

SAMPLE EXTRACTION

Magnetic susceptibility samples consist of sediment packed in plastic cubes 2 x 2 cm square and either 1.8 cm or 2.4 cm high. Because I planned to archive these samples in the cubes for other possible future studies, considerable care was taken to avoid sample cross-contamination. Extraction tools were washed, first in tap water, then in commercially produced distilled water after each sample extraction. Sample cubes were weighed before and after packing, first on an electronic balance and then on a Mettler analytical balance (to 0.00001 g). Most samples were passed through a coarse, 2.7 mm nylon mesh before packing with a plastic tamper. Samples 49-81 were passed through a number 6 geologic sieve (3.36 mm mesh) and tamped with iron tools. Large snail shell fragments, rhizoconcretions, and chert or sandstone clasts retained on the sieve were removed. Most analysts advocate using raw, unsieved sediment samples, but the procedure used here prevents the chance inclusion of large clastic items that might unduly influence the magnetic signature of the sediment.

SAMPLE MEASUREMENT

Samples were run in two batches, the first on April 24, 1996, and the second on September 1, 1998 (Table A3.1), with only slight differences in procedure. The first batch used 4-gram cubes holding about 7-8 g of sediment; the second batch used slightly larger 6-gram cubes holding about 9.8 g of sediment. Measurements were done on a Bartington MS2 system at the University of Texas Department of Geological Sciences. Chi values are reported in Gaussian units, or cgs (centimeters/gram/second). The measurement device has a resolution of 2 x 10E-7 cgs at low frequency. Four determinations (two at low frequency and two again at high frequency) were run on each sample. In the first batch, low frequency samples were run at 0.465 kHz for 1.2 seconds

(0.1 sensitivity on the instrument), high frequency at 4.65 kHz for 12 seconds (1.0 sensitivity on the instrument). The second batch was run at a sensitivity of 1.0. The measurement software automatically averages the two readings for each sample and subtracts the background reading.

VALUES

Three values were computed for each sample:

X_{lf} = (low-freq reading * 7.36)/ sample wt in g

X_{hf} = (hi-freq reading * 7.36)/ sample wt in g

$Xfd = ((X_{lf} - X_{hf}) * 100)/ X_{lf}$

X_{lf} is the *low-frequency chi value*; X_{hf} is the *high-frequency chi value*. Xfd is the *coefficient of frequency determination*, a measure of the extent to which changing the measurement frequency changes the strength of the magnetic signal, and an indicator of the presence of ultrafine grains of magnetic material (Dalan and Banerjee 1998:6; Gale and Hoare 1991:207).

Chi values in SI (Systeme International) units can be converted to cgs units by the formula

$X_{cgs} = 4 n X_{si}$

Table A3.1: Provenience Data for Magnetic Susceptibility Samples.

Sample	Unit	Level	Analysis date	Stratum	Description
1	not used				
2	N109 E103	92.90-92.85	4/24/96	2D	phytopol
3	N109 E103	92.85-92.80	4/24/96	2D	phytopol
4	N109 E103	92.80-92.75	4/24/96	2D	phytopol
5	N109 E103	92.75-92.70	4/24/96	2D	phytopol
6	N109 E103	92.70-92.65	4/24/96	2D	phytopol
7	N109 E103	92.65-92.60	4/24/96	2C	phytopol
8	N109 E103	92.60-92.55	4/24/96	2C	phytopol
9	N109 E103	92.55-92.50	4/24/96	2B	phytopol
10	N109 E103	92.50-92.45	4/24/96	2B	phytopol
11	N109 E103	92.45-92.40	4/24/96	2B	phytopol
12	N109 E103	92.40-92.35	4/24/96	2B	phytopol
13	N109 E103	92.35-92.30	4/24/96	2B	phytopol
14	N109 E103	92.30-92.25	4/24/96	2B	phytopol
15	N109 E103	92.25-92.20	4/24/96	2B	phytopol
16	N109 E103	92.20-92.15	4/24/96	2B/2A	phytopol
17	N109 E103	92.15-92.10	4/24/96	2A	phytopol
18	N109 E103	92.10-92.05	4/24/96	2A	phytopol
19	N109 E103	92.05-92.00	4/24/96	2A/1	phytopol
20	N109 E103	92.00-91.95	4/24/96	1	phytopol
21	N109 E103	91.95-91.90	4/24/96	1	phytopol
22	N110 E102	92.90-92.80U	4/24/96	2D	phytopol
23	N110 E102	92.90-92.80L	4/24/96	2D	phytopol
24	N110 E102	92.80-92.75	4/24/96	2D	phytopol
25	N110 E102	92.75-92.70	4/24/96	2D/2C	phytopol
26	N110 E102	92.70-92.65	4/24/96	2C	phytopol
27	N110 E102	92.65-92.60	4/24/96	2C	phytopol
28	N110 E102	92.60-92.55	4/24/96	2C	phytopol
29	N110 E102	92.55-92.50	4/24/96	2C/2B	phytopol
30	N110 E102	92.50-92.45	4/24/96	2B	phytopol
31	N110 E102	92.45-92.40	4/24/96	2B	phytopol
32	N110 E102	92.40-92.35	4/24/96	2B	phytopol
33	N110 E102	92.35-92.30	4/24/96	2B	phytopol
34	N110 E102	92.30-92.25	4/24/96	2B	phytopol
35	N110 E102	92.25-92.20	4/24/96	2B	phytopol
36	N110 E102	92.20-92.15	4/24/96	2B	phytopol
37	N110 E102	92.15-92.10	4/24/96	2A	phytopol
38	N110 E102	92.10-92.05	4/24/96	2A	phytopol
39	N110 E102	92.05-92.00	4/24/96	2A	phytopol
40	N110 E102	92.00-91.95	4/24/96	2A/carb	phytopol
41	N110 E102	91.95-91.90	4/24/96	carb	phytopol
42	N110 E102	91.90-91.85	4/24/96	carb	pollen aliquot
43	N110 E102	91.85-91.80	4/24/96	1	phytopol
44	N110 E102	91.80-91.75	4/24/96	1	phytopol
45	N110 E102	91.75-91.70	4/24/96	1	phytopol

(Table A3.1, continued)

Sample	Unit	Level	Analysis date	Stratum	Description
46	N110 E102	91.70-91.65	4/24/96	1	phytopol
47	N110 E102	91.65-91.60	4/24/96	1	phytopol
48	N110 E102	91.60-91.55	4/24/96	1	phytopol
49	N111 E101	92.89-92.80	4/24/96	2D	phytopol
50	N111 E101	92.80-92.70	4/24/96	2D	phytopol
51	N111 E101	92.70-92.65	4/24/96	2C	CVS matrix
52	N111 E101	92.65-92.60	4/24/96	2C	phytopol
53	N111 E101	92.60-92.55	4/24/96	2C/2B	phytopol
54	N111 E101	92.55-92.50	4/24/96	2B	phytopol
55	N111 E101	92.50-92.45	4/24/96	2B	phytopol
56	N111 E101	92.45-92.40	4/24/96	2B	phytopol
57	N111 E101	92.40-92.35	4/24/96	2B	phytopol
58	N111 E101	92.35-92.30	4/24/96	2B	phytopol
59	N111 E101	92.30-92.25	4/24/96	2B	phytopol
60	N111 E101	92.25-92.20	4/24/96	2B	phytopol
61	N111 E101	92.20-92.15	4/24/96	2B/2A	phytopol
62	N111 E101	92.15-92.10	4/24/96	2A	phytopol
63	N111 E101	92.10-92.05	4/24/96	2A	phytopol
64	N111 E101	92.05-92.00	4/24/96	2A	phytopol
65	N111 E101	92.00-91.95	4/24/96	2A/1	phytopol
66	N111 E101	91.95-91.90	4/24/96	1	phytopol
67	not used				
68	N112 E99	92.60-92.55	4/24/96	2D/2C	phytopol
69	N112 E99	92.55-92.50	4/24/96	2B	phytopol
70	N112 E99	92.50-92.45	4/24/96	2B	phytopol
71	N112 E99	92.45-92.40	4/24/96	2B	phytopol
72	N112 E99	92.40-92.35	4/24/96	2B	phytopol
73	N112 E99	92.35-92.30	4/24/96	2B/2A	phytopol
74	N112 E99	92.30-92.25	4/24/96	2A	phytopol
75	N112 E99	92.25-92.20	4/24/96	2A	phytopol
76	N112 E99	92.20-92.15	4/24/96	2A	phytopol
77	N112 E99	92.15-92.10	4/24/96	2A	phytopol
78	N112 E99	92.10-92.05	4/24/96	1	phytopol
79	N112 E99	92.05-92.00	4/24/96	1	phytopol
80	N112 E99	92.00-91.95	4/24/96	1	phytopol
81	N112 E99	91.95-91.90	4/24/96	1	phytopol
82	N113 E98	92.72-92.50	9/1/98	2C?	phytopol
83	N113 E98	92.50-92.40	9/1/98	2B	phytopol
84	N113 E98	92.40-92.30	9/1/98	2B/2A	phytopol
85	N113 E98	92.30-92.20	9/1/98	2A	phytopol
86	N113 E98	92.20-92.15	9/1/98	2A	phytopol
87	N113 E98	92.15-92.10	9/1/98	2A	phytopol

(Table A3.1, continued)

Sample	Unit	Level	Analysis date	Stratum	Description
100	N97 E96	99.75	9/1/98	5B	upper deposits 4/17/81
101	N97 E96	99.50	9/1/98	5B	upper deposits 4/17/81
102	N97 E96	99.25	9/1/98	5A	upper deposits 4/17/81
103	N97 E96	99.00	9/1/98	5A	upper deposits 4/17/81
104	N97 E96	98.75	9/1/98	4	upper deposits 4/17/81
105	N97 E96	98.55	9/1/98	4	upper deposits 4/17/81
106	N97 E96	98.45	9/1/98	4	upper deposits 4/17/81
107	N97 E96	98.25	9/1/98	4	upper deposits 4/17/81
108	N97 E96	98.00	9/1/98	4	upper deposits 4/17/81
109	N97 E96	97.75	9/1/98	4	upper deposits 4/17/81
110	N111 E101	91.99	4/24/96	2A?	Feature 6 fill
111	N111 E101	92.00-91.95	4/24/96	2A/1	matrix adjacent F6
112	cutbank	93.45-93.40	4/24/96	2E	sediment sample
113	cutbank	93.35-93.30	4/24/96	2E	sediment sample
114	cutbank	93.30-93.25	4/24/96	2E	sediment sample
115	cutbank	93.40-93.35	4/24/96	2E	sediment sample
130	N109 E96	93.00-92.95	9/1/98	2D3	phytopol
131	N109 E96	92.95-92.90	9/1/98	2D3	phytopol
132	N109 E96	92.90-92.85	9/1/98	2D3	phytopol
133	N109 E96	92.85-92.80	9/1/98	2D3/D2	phytopol
134	N109 E96	92.80-92.75	9/1/98	2D2	phytopol
135	N109 E96	92.75-92.70	9/1/98	2D2	phytopol
136	N109 E96	92.70-92.65	9/1/98	2D2	phytopol
137	N109 E96	92.65-92.60	9/1/98	2D1	phytopol
138	N109 E96	92.60-92.55	9/1/98	2D1	phytopol
139	N109 E96	92.55-92.50	9/1/98	2D1	phytopol
140	N109 E96	92.50-92.45	9/1/98	2C	phytopol *
141	N109 E96	92.45-92.40	9/1/98	2C	phytopol
142	N109 E96	92.40-92.35	9/1/98	2C	phytopol
143	N109 E96	92.35-92.30	9/1/98	2B	phytopol
143A	N109 E96	92.35-92.30	9/1/98	2C?	Feature 7 fill
144	N109 E96	92.30-92.25	9/1/98	2B/2A	phytopol
145	N109 E96	92.25-92.20	9/1/98	2A	southwest corner
145A	N109 E96	92.25-92.20	9/1/98	2A	southeast corner
146	N109 E96	92.20-92.15	9/1/98	2A	phytopol
147	N109 E96	92.15-92.10	9/1/98	2A	phytopol
147A	N109 E96	92.14-92.12	9/1/98	lens	orange limey sand, E wall
147B	N109 E96	92.135-92.115	9/1/98	lens	gray limey sand, N wall
148	N109 E96	92.10-92.05	9/1/98	silt	phytopol
149	N109 E96	92.05-92.00	9/1/98	silt	phytopol
149A	N109 E96	92.05-92.04	9/1/98	silt	silt deposit, SW corner
149B	N109 E96	92.05-92.02	9/1/98	lens	packed caliche, chert pebbles, sand, NE corner

Table A3.2: Magnetic Susceptibility Data.

Sample	Sample weight (g)	Low-freq. reading	High-freq. reading	Low-freq. chi value	High-freq chi value	Coefficient of frequency dependence
1	not used					
2	7.01107	6.1	5.0	6.403587	5.24884219	18.03278
3	6.94009	5.4	4.5	5.726726	4.77227241	16.66666
4	6.66272	4.0	4.0	4.418615	4.41861582	0
5	7.06618	3.95	3.5	4.114245	3.64553408	11.39240
6	6.77004	3.8	3.5	4.131142	3.80499968	7.894736
7	6.80394	4.95	5.0	5.354544	5.40863088	-1.01010
8	6.65091	5.0	5.0	5.533077	5.53307743	0
9	6.76547	4.2	4.0	4.569083	4.35150847	4.761904
10	6.79473	4.7	5.0	5.091004	5.41596208	-6.38297
11	6.90865	4.549	4.5	4.846191	4.79399014	1.077159
12	6.58726	4.9	6.0	5.474810	6.70384955	-22.4489
13	6.9355	4.95	5.5	5.252973	5.83663759	-11.1111
14	6.61177	4.75	4.0	5.287540	4.45266547	15.78947
15	6.50552	4.5	3.5	5.091061	3.95971421	22.22222
16	6.58442	4.35	4.5	4.862387	5.03005580	-3.44827
17	6.77092	5.1	5.0	5.543707	5.43500735	1.960784
18	6.93043	5.45	5.5	5.787808	5.84090742	-0.91743
19	6.93013	5.45	5.0	5.788058	5.31014570	8.256880
20	6.75463	4.7	5.0	5.121227	5.44811485	-6.38297
21	6.28192	3.899	4.0	4.568132	4.68646528	-2.59040
22	7.24542	5.2	5.0	5.282233	5.07907064	3.846153
23	7.41974	4.75	5.0	4.711755	4.95974252	-5.26315
24	7.45464	4.35	4.0	4.294774	3.94921821	8.045976
25	7.42293	4.5	4.5	4.461849	4.46184997	0
26	7.38006	4.2	3.5	4.188583	3.49048653	16.66666
27	7.07384	5.5	4.5	5.722493	4.68203974	18.18181
28	7.25847	5.799	5.0	5.880115	5.06993898	13.77823
29	7.03846	5.65	5.0	5.908110	5.22841644	11.50442
30	6.95682	5.25	4.0	5.554261	4.23181856	23.80952
31	7.12376	5.5	4.5	5.682392	4.64923018	18.18181
32	7.45638	5.049	5.0	4.983737	4.93537078	0.970489
33	7.35064	5.299	5.0	5.305747	5.00636679	5.642574
34	7.45303	5.149	5.5	5.084729	5.43134806	-6.81685
35	7.15683	5.1	4.0	5.244780	4.11355307	21.56862
36	7.18585	5.35	5.0	5.479657	5.12117564	6.542056
37	7.08905	6.4	5.0	6.644613	5.19110459	21.87500
38	6.84246	5.75	4.0	6.184910	4.30254616	30.43478
39	6.84852	5.149	4.5	5.533551	4.83608137	12.60438
40	6.5618	4.5	2.0	5.047395	2.24328690	55.55555

(Table A3.2, continued)

Sample	Sample weight (g)	Low-freq. reading	High-freq. reading	Low-freq. chi value	High-freq. chi value	Coefficient of frequency dependence
41	6.60965	4.1	3.5	4.565445	3.89733193	14.63414
42	6.99701	3.95	4.0	4.154917	4.20751149	-1.26582
43	6.72615	4.799	4.5	5.251241	4.92406503	6.230464
44	6.46087	4.75	4.5	5.411035	5.12624461	5.263157
45	6.64964	3.7	3.5	4.095259	3.87389393	5.405405
46	7.35669	3.649	3.5	3.650641	3.50157476	4.083310
47	7.11498	2.8	2.5	2.896424	2.58609300	10.71428
48	6.94462	3.1	2.5	3.285420	2.64953302	19.35483
49	7.44938	4.85	4.5	4.791808	4.44600759	7.216494
50	7.05585	4.4	4.0	4.589666	4.17242430	9.090909
51	7.57599	5.85	5.5	5.683217	5.34319607	5.982906
52	7.22159	5.95	6.0	6.064038	6.11499684	-0.84033
53	6.91763	5.7	5.0	6.064504	5.31974101	12.28070
54	7.26258	5.799	5.5	5.876787	5.57377681	5.156061
55	7.50286	6.149	6.0	6.031918	5.88575557	2.423158
56	7.59634	5.6	5.0	5.425770	4.84443824	10.71428
57	7.27968	5.7	5.0	5.762890	5.05516726	12.28070
58	7.89489	6.2	6.5	5.779941	6.05961578	-4.83870
59	7.74735	6.1	5.0	5.795013	4.75001129	18.03278
60	7.389	6.049	6.0	6.025259	5.97645148	0.810051
61	7.18047	6.1	5.0	6.252515	5.12501271	18.03278
62	7.12143	6.95	7.0	7.182827	7.23450206	-0.71942
63	6.76324	6.299	6.0	6.854797	6.52941490	4.746785
64	7.25146	5.75	5.5	5.836066	5.58232411	4.347826
65	6.54356	5.2	5.0	5.848804	5.62385001	3.846153
66	6.77296	4.799	4.5	5.214948	4.89003331	6.230464
67	not used					
68	6.93184	4.9	4.5	5.202659	4.77795217	8.163265
69	7.0749	5.25	5.0	5.461561	5.20148695	4.761904
70	7.07156	5.7	5.0	5.932495	5.20394368	12.28070
71	7.46479	5.35	5.0	5.274897	4.92981048	6.542056
72	7.02869	5.2	4.5	5.445111	4.71211563	13.46153
73	7.33128	4.95	5.0	4.969391	5.01958730	-1.01010
74	7.41293	5.5	5.0	5.460728	4.96429887	9.090908
75	7.41018	6.0	5.0	5.959369	4.96614117	16.66666
76	7.1109	6.2	5.0	6.417190	5.17515364	19.35483
77	6.38197	5.7	5.5	6.573518	6.34286905	3.508772
78	6.83777	5.65	5.0	6.081514	5.38187158	11.50442
79	6.23463	5.049	5.0	5.960360	5.90251547	0.970489
80	6.10154	4.25	4.5	5.126574	5.42813781	-5.88235
81	6.53817	4.95	4.0	5.572201	4.50278901	19.19191
82	9.83428	6.5	5.5	4.864616	4.11621389	15.38461
83	9.99085	7.0	6.5	5.156718	4.78838136	7.142857
84	10.06379	5.0	6.0	3.656674	4.38800889	-20
85	10.05082	8.0	6.5	5.858228	4.75981064	18.75

(Table A3.2, continued)

Sample	Sample weight (g)	Low-freq. reading	High-freq. reading	Low-freq. chi value	High-freq. chi value	Coefficient of frequency dependence
86	9.28217	8.5	7.5	6.739803	5.94688526	11.76470
87	9.50694 8.0	8.0	7.0	6.193370	5.41919902	12.5
100	8.72858	10.5	9.5	8.853673	8.01046676	9.523809
101	9.02297	10.5	10.0	8.564807	8.15695940	4.761904
102	9.94205	10.5	8.5	7.773044	6.29246483	19.04761
103	10.43977	7.0	8.0	4.934974	5.63997099	-14.2857
104	10.39378	7.0	6.5	4.956810	4.60275280	7.142857
105	10.01876	5.0	4.5	3.673109	3.30579832	10
106	10.12618	5.0	4.5	3.634144	3.27072992	10
107	9.86748	5.5	4.5	4.102364	3.35648007	18.18181
108	10.19119	7.0	6.0	5.055346	4.33315442	14.28571
109	9.9283	7.0	6.0	5.189206	4.44789138	14.28571
110	6.762	5.25	4.5	5.714285	4.89795918	14.28571
111	7.092	5.1	4.5	5.292724	4.67005076	11.76470
112	8.20965	4.149	3.5	3.719603	3.13777079	15.64232
113	8.61856	3.95	3.5	3.373185	2.98889838	11.39240
114	8.43843	3.7	3.0	3.227140	2.61660048	18.91891
115	8.59595	4.6	4.5	3.938598	3.85297727	2.173913
130	9.51783	8.0	6.5	6.186284	5.02635579	18.75
131	9.82151	8.5	7.0	6.369692	5.24562923	17.64705
132	9.78782	8.5	7.5	6.391617	5.63966236	11.76471
133	9.71501	8.0	7.0	6.060725	5.30313402	12.50
134	9.46326	3.0	7.0	2.333234	5.44421267	-133.333
135	9.34355	3.5	6.0	2.756982	4.72625501	-71.42857
136	9.62684	7.0	6.5	5.351704	4.96943961	7.142857
137	8.94736	6.5	6.5	5.346829	5.34682856	0
138	9.45149	7.5	6.5	5.840348	5.06163578	13.33333
139	9.45761	6.5	6.5	5.058360	5.05836041	0
140	9.25692	7.0	7.0	5.565566	5.56556608	0
141	9.2037	8.0	7.5	6.397427	5.99758792	6.25
142	9.13971		7.5		6.03957893	
143	9.62539	7.5	6.0	5.734832	4.58786605	20
143A	9.42261	6.5	7.0	5.077149	5.46769950	-7.69230
144	9.68534	6.0	5.0	4.559468	3.79955685	16.66666
145	10.05701	7.0	7.0	5.122794	5.12279494	0
145A	10.5327	5.5	5.0	3.843269	3.49388096	9.090909
146	9.33829	6.5	7.0	5.122993	5.51707004	-7.69230
147	9.49974	8.0	7.998	6.198064	6.19651485	0.025
147A	11.43803	4.5	3.5	2.895603	2.25213607	22.22222
147B	11.94834	4.0	4.0	2.463940	2.46394059	0
148	9.05847	7.5	7.0	6.093744	5.68749468	6.666666
149	9.64935	8.5	7.0	6.483338	5.33921974	17.64705
149A	10.44288	4.5	8.0	3.171538	5.63829135	-77.7777
149B	11.16072	4.5	4.5	2.967550	2.96755048	0

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Appendix 4: Items Recovered From the Quarter-Inch Screen

COUNTS AND WEIGHTS OF ITEMS

Level	Stratum	Level volume (m^3)	Snail count	Chert gravel count	Rhizoconcretion weight (g)	FeMn concretion count	Sandstone + caliche nodule weight (g)
N109 E103							
93.14-92.90	2D/3	0.1225	659	220	1529.2	7	302.7
92.90-92.85	2D/3	0.05	307	129	627	5	89.7
92.85-92.80	2D	0.05	260	141	487.4	9	83.6
92.80-92.75	2D	0.05	163	127	447.6	14	61.8
92.75-92.70	2D	0.05	183	189	455.9	16	33.7
92.70-92.65	2D	0.05	131	69	630.2	4	28.7
92.65-92.60	2C/2D	0.05	104	25	448.7	4	20.3
92.60-92.55	2C	0.05	68	38	548	2	19.7
92.55-92.50	2B/2C	0.05	5	40	579.6	2	31.4
92.50-92.45	2B	0.05	32	16	631.4	3	55
92.45-92.40	2B	0.05	37	12	383.6	3	66.9
92.40-92.35	2B	0.05	17	13	248.5	2	35.9
92.35-92.30	2B	0.05	12	6	143.9	0	13.1
92.30-92.25	2B	0.05	19	6	168.4	0	79.6
92.25-92.20	2B	0.05	16	5	359.7	0	3.8
92.20-92.15	2A/2B	0.05	22	1	814.4	2	1.4
92.15-92.10	2A	0.05	47	3	705.1	0	1.4
92.10-92.05	2A	0.05	9	2	562.8	0	0
92.05-92.00	1/2A	0.05	12	4	1645.9	0	0.9
92.00-91.95	1	0.05	5	1	1503.7	0	0
91.95-91.90	1	0.05	0	7	984.2	0	1.5
N110 E102							
93.08-92.90	3*	0.0475	109	95	647.6	6	105.7
92.90-92.80	2D/3	0.1	110	212	1189.1	16	192.3
92.80-92.75	2D	0.05	209	120	701.8	7	82.9
92.75-92.70	2D	0.05	60	72	383.7	6	50.1
92.70-92.65	2C	0.05	59	26	472.2	5	31.7
92.65-92.60	2C	0.05	91	17	350.6	1	10.7
92.60-92.55	2B/2C	0.05	31	17	505.7	0	27.2
92.55-92.50	2B/2C	0.05	11	28	401	0	27.3
92.50-92.45	2B	0.05	22	19	599.1	1	77.1
92.45-92.40	2B	0.05	11	17	339.2	1	57
92.40-92.35	2B	0.05	14	23	269.6	4	84.9
92.35-92.30	2B	0.05	5	19	292.3	1	61.4
92.30-92.25	2B	0.05	6	13	365.5	0	50.5
92.25-92.20	2A/2B	0.05	6	11	354.2	0	87.3
92.20-92.15	2A/2B	0.05	29	7	534.8	2	26.5
92.15-92.10	2A	0.05	33	8	530.3	3	22
92.10-92.05	2A	0.05	2	10	677.3	1	50.3
92.05-92.00	2A	0.05	5	10	836.2	0	16.1

(continued from previous page)

Level	Stratum	Level volume (m^3)	Snail count	Chert gravel count	Rhizoconcretion weight (g)	FeMn concretion count	Sandstone + caliche nodule weight (g)
(N110 E102, continued)							
92.00-91.95	2A/2A cal	0.05	1	9	1865.9	1	4.8
91.95-91.90	2A cal	0.05	2	3	2105	0	2
91.90-91.85	1/2A cal	0.05	0	5	1136.8	1	2
91.85-91.80	1	0.05	0	11	813.3	1	2.4
91.80-91.75	1	0.05	0	25	71.5	2	10.2
91.75-91.70	1	0.05	0	258	60.2	11	199.6
91.70-91.65	1	0.05	0	428	37.9	22	252.8
91.65-91.60	1	0.05	0	91	27.3	4	67.5
91.60-91.55	1	0.05	0	5	38.6	1	8
N111 E101							
92.89-92.80	2D/3	0.01	40	8	157.3	2	9.8
92.80-92.70	2D	0.1	247	78	1853.9	4	82
92.70-92.65	2C/2D	0.05	62	14	700	0	13.1
92.65-92.60	2C	0.05	140	12	674.3	0	28.1
92.60-92.55	2B/2C	0.05	59	19	879.3	2	250.9
92.55-92.50	2B	0.05	77	21	1276.6	1	186.8
92.50-92.45	2B	0.05	11	10	1018.1	1	55.8
92.45-92.40	2B	0.05	9	7	533.4	2	51.4
92.40-92.35	2B	0.05	5	9	464.9	1	21.4
92.35-92.30	2B	0.05	19	3	489.4	0	11
92.30-92.25	2B	0.05	8	4	475.9	1	11.9
92.25-92.20	2A/2B	0.05	9	3	642.6	0	4.9
92.20-92.15	2A	0.05	8	18	819.9	0	2.3
92.15-92.10	2A	0.05	17	117	1255.4	0	11.5
92.10-92.05	2A	0.05	2	33	1758.1	3	38
92.05-92.00	2A	0.05	0	13	1859.4	1	17.9
92.00-91.95	1/2A	0.05	0	13	1714	1	3.7
91.95-91.90	1	0.05	0	15	4616.2	1	7.1
N112 E99							
92.89-92.60	2C/2D	0.1033	173	71	2333.3	9	148.6
92.60-92.55	2B/2C	0.05	27	22	911.8	2	96.6
92.55-92.50	2B	0.05	28	18	1149.5	1	113.9
92.50-92.45	2B	0.05	20	14	975.5	2	113.4
92.45-92.40	2B	0.05	11	16	471.8	1	88.2
92.40-92.35	2B	0.05	3	8	719	0	50.4
92.35-92.30	2A/2B	0.05	4	46	311.2	3	124.2
92.30-92.25	2A/2B	0.05	6	16	335.2	0	26.8
92.25-92.20	2A	0.05	10	4	686.2	0	1.4
92.20-92.15	2A	0.05	10	4	609.2	0	0
92.15-92.10	2A	0.05	6	1	474.3	1	2.6
92.10-92.05	1/2A	0.05	1	1	725.4	0	0
92.05-92.00	1	0.05	0	4	1240.9	0	0.8
92.00-91.95	1	0.05	0	8	2175.6	1	0.3
91.95-91.90	1	0.05	0	5	4071.2	0	0.8

(continued from previous page)

Level	Stratum	Level volume (m^3)	Snail count	Chert gravel count	Rhizoconcretion weight (g)	FeMn concretion count	Sandstone + caliche nodule weight (g)
N113 E98							
92.72-92.50	2C	0.0897					
92.50-92.40	2B	0.10					
92.40-92.30	2A/2B	0.10					
92.30-92.20	2A	0.10					
92.20-92.15	2A	0.05					
92.15-92.10	2A	0.05					
Unit 2							
92.68-92.38	2B/2C	0.0950					
N112 E97							
93.14-92.75	2D/3	0.2971	1560	784	5094.4	52	689.4
92.75-92.70	2C/2D	0.05	131	35	778.9	0	95.1
92.70-92.65	2C	0.05	94	30	800.6	3	94.2
92.65-92.60	2C	0.05	60	45	1082.2	5	127.7
92.60-92.55	2B/2C	0.05		55	759.3	6	162.9
92.55-92.50	2B	0.05	13	54	740.2	3	223.4
92.50-92.45	2B	0.05	5	37	535.4	0	179.1
92.45-92.40	2B	0.05	7	34	593.3	5	118.3
92.40-92.35	2B	0.05	0	24	244.2	0	32.3
92.35-92.30	2B	0.05	6	53	496.4	7	89.2
92.30-92.25	2A/2B	0.05	4	17	435.3	0	17.2
92.25-92.20	2A	0.05	13	3	678.3	2	14
92.20-92.15	2A	0.05	0	2	790.4	0	2.2
N109 E96							
93.08-93.00	2D	0.0475	422	152	667.3	3	265.1
93.00-92.95	2D	0.05	280	225	657.4	3	157.7
92.95-92.90	2D	0.05	188	144	552.9	6	99.8
92.90-92.85	2D	0.05	265	124	664.2	6	257.3
92.85-92.80	2D	0.05	465	115	810.7	4	806.2
92.80-92.75	2D	0.05	344	87	833.1	7	760.5
92.75-92.70	2D	0.05	210	103	869.6	3	577.4
92.70-92.65	2D	0.05	229	110	792	12	686.9
92.65-92.60	2D	0.05	122	135	279.4	10	683.6
92.60-92.55	2D	0.05	96	272	334.9	17	622.1
92.55-92.50	2C/2D	0.05	107	247	355.4	16	666.8
92.50-92.45	2C	0.05	120	370	310	16	881.2
92.45-92.40	2C	0.05	90	343	410.5	25	872.1
92.40-92.35	2B/2C	0.05	28	124	180.8	9	371
92.35-92.30	2B	0.05	16	72	162.5	0	137.8
92.30-92.25	2B	0.05	30	375	240.4	20	985.2
92.25-92.20	2A	0.05	5	992	259.3	52	1889.7
92.20-92.15	2A	0.05	3	1285	653.8	48	2174.2
92.15-92.10	2A	0.05	2	374	614	29	1242.7
92.10-92.05	2A	0.05	8	779	893.6	47	1296.9
92.05-92.00	2A	0.05	4	1365	876.2	35	1634.4

ITEM DENSITIES (COUNTS OR WEIGHTS BY EXCAVATED VOLUME)

Level	Stratum	Level vol. (m^3)	Snail density (ct./m^3)	Gravel density (ct./m^3)	Rhizoconcre-tion density (wt. in g/m^3)	FeMn concretion density (ct./m^3)	Sandstone + caliche nodule density (g/m^3)
N109 E103							
93.14-92.90	2D/3	0.1225	5379.592	1795.918	12483.265	57.143	2471.020
92.90-92.85	2D/3	0.05	6140.000	2580.000	12540.000	100.000	1794.000
92.85-92.80	2D	0.05	5200.000	2820.000	9748.000	180.000	1672.000
92.80-92.75	2D	0.05	3260.000	2540.000	8952.000	280.000	1236.000
92.75-92.70	2D	0.05	3660.000	3780.000	9118.000	320.000	674.000
92.70-92.65	2D	0.05	2620.000	1380.000	12604.000	80.000	574.000
92.65-92.60	2C/2D	0.05	2080.000	500.000	8974.000	80.000	406.000
92.60-92.55	2C	0.05	1360.000	760.000	10960.000	40.000	394.000
92.55-92.50	2B/2C	0.05	100.000	800.000	11592.000	40.000	628.000
92.50-92.45	2B	0.05	640.000	320.000	12628.000	60.000	1100.000
92.45-92.40	2B	0.05	740.000	240.000	7672.000	60.000	1338.000
92.40-92.35	2B	0.05	340.000	260.000	4970.000	40.000	718.000
92.35-92.30	2B	0.05	240.000	120.000	2878.000	0.000	262.000
92.30-92.25	2B	0.05	380.000	120.000	3368.000	0.000	1592.000
92.25-92.20	2B	0.05	320.000	100.000	7194.000	0.000	76.000
92.20-92.15	2A/2B	0.05	440.000	20.000	16288.000	40.000	28.000
92.15-92.10	2A	0.05	940.000	60.000	14102.000	0.000	28.000
92.10-92.05	2A	0.05	180.000	40.000	11256.000	0.000	0.000
92.05-92.00	1/2A	0.05	240.000	80.000	32918.000	0.000	18.000
92.00-91.95	1	0.05	100.000	20.000	30074.000	0.000	0.000
91.95-91.90	1	0.05	0.000	140.000	19684.000	0.000	30.000
N110 E102							
93.08-92.90	3*	0.0475	2294.737	2000.000	13633.684	126.316	2225.263
92.90-92.80	2D/3	0.1	1100.000	2120.000	11891.000	160.000	1923.000
92.80-92.75	2D	0.05	4180.000	2400.000	14036.000	140.000	1658.000
92.75-92.70	2D	0.05	1200.000	1440.000	7674.000	120.000	1002.000
92.70-92.65	2C	0.05	1180.000	520.000	9444.000	100.000	634.000
92.65-92.60	2C	0.05	1820.000	340.000	7012.000	20.000	214.000
92.60-92.55	2B/2C	0.05	620.000	340.000	10114.000	0.000	544.000
92.55-92.50	2B/2C	0.05	220.000	560.000	8020.000	0.000	546.000
92.50-92.45	2B	0.05	440.000	380.000	11982.000	20.000	1542.000
92.45-92.40	2B	0.05	220.000	340.000	6784.000	20.000	1140.000
92.40-92.35	2B	0.05	280.000	460.000	5392.000	80.000	1698.000
92.35-92.30	2B	0.05	100.000	380.000	5846.000	20.000	1228.000
92.30-92.25	2B	0.05	120.000	260.000	7310.000	0.000	1010.000
92.25-92.20	2A/2B	0.05	120.000	220.000	7084.000	0.000	1746.000
92.20-92.15	2A/2B	0.05	580.000	140.000	10696.000	40.000	530.000
92.15-92.10	2A	0.05	660.000	160.000	10606.000	60.000	440.000
92.10-92.05	2A	0.05	40.000	200.000	13546.000	20.000	1006.000
92.05-92.00	2A	0.05	100.000	200.000	16724.000	0.000	322.000
92.00-91.95	2A/2A cal	0.05	20.000	180.000	37318.000	20.000	96.000
91.95-91.90	2A cal	0.05	40.000	60.000	42100.000	0.000	40.000
91.90-91.85	1/2A cal	0.05	0.000	100.000	22736.000	20.000	40.000
91.85-91.80	1	0.05	0.000	220.000	16266.000	20.000	48.000

(continued from previous page)

Level	Stratum	Level vol. (m^3)	Snail density (ct./m^3)	Gravel density (ct./m^3)	Rhizoconcretion density (wt. in g/m^3)	FeMn concretion density (ct./m^3)	Sandstone + caliche nodule density (g/m^3)
(N110 E102, continued)							
91.80-91.75	1	0.05	0.000	500.000	1430.000	40.000	204.000
91.75-91.70	1	0.05	0.000	5160.000	1204.000	220.000	3992.000
91.70-91.65	1	0.05	0.000	8560.000	758.000	440.000	5056.000
91.65-91.60	1	0.05	0.000	1820.000	546.000	80.000	1350.000
91.60-91.55	1	0.05	0.000	100.000	772.000	20.000	160.000
N111 E101							
92.89-92.80	2D/3	0.01	4000.000	800.000	15730.000	200.000	980.000
92.80-92.70	2D	0.1	2470.000	780.000	18539.000	40.000	820.000
92.70-92.65	2C/2D	0.05	1240.000	280.000	14000.000	0.000	262.000
92.65-92.60	2C	0.05	2800.000	240.000	13486.000	0.000	562.000
92.60-92.55	2B/2C	0.05	1180.000	380.000	17586.000	40.000	5018.000
92.55-92.50	2B	0.05	1540.000	420.000	25532.000	20.000	3736.000
92.50-92.45	2B	0.05	220.000	200.000	20362.000	20.000	1116.000
92.45-92.40	2B	0.05	180.000	140.000	10668.000	40.000	1028.000
92.40-92.35	2B	0.05	100.000	180.000	9298.000	20.000	428.000
92.35-92.30	2B	0.05	380.000	60.000	9788.000	0.000	220.000
92.30-92.25	2B	0.05	160.000	80.000	9518.000	20.000	238.000
92.25-92.20	2A/2B	0.05	180.000	60.000	12852.000	0.000	98.000
92.20-92.15	2A	0.05	160.000	360.000	16398.000	0.000	46.000
92.15-92.10	2A	0.05	340.000	2340.000	25108.000	0.000	230.000
92.10-92.05	2A	0.05	40.000	660.000	35162.000	60.000	760.000
92.05-92.00	2A	0.05	0.000	260.000	37188.000	20.000	358.000
92.00-91.95	1/2A	0.05	0.000	260.000	34280.000	20.000	74.000
91.95-91.90	1	0.05	0.000	300.000	92324.000	20.000	142.000
N112 E99							
92.89-92.60	2C/2D	0.1033	1674.734	687.318	22587.609	87.125	1438.529
92.60-92.55	2B/2C	0.05	540.000	440.000	18236.000	40.000	1932.000
92.55-92.50	2B	0.05	560.000	360.000	22990.000	20.000	2278.000
92.50-92.45	2B	0.05	400.000	280.000	19510.000	40.000	2268.000
92.45-92.40	2B	0.05	220.000	320.000	9436.000	20.000	1764.000
92.40-92.35	2B	0.05	60.000	160.000	14380.000	0.000	1008.000
92.35-92.30	2A/2B	0.05	80.000	920.000	6224.000	60.000	2484.000
92.30-92.25	2A/2B	0.05	120.000	320.000	6704.000	0.000	536.000
92.25-92.20	2A	0.05	200.000	80.000	13724.000	0.000	28.000
92.20-92.15	2A	0.05	200.000	80.000	12184.000	0.000	0.000
92.15-92.10	2A	0.05	120.000	20.000	9486.000	20.000	52.000
92.10-92.05	1/2A	0.05	20.000	20.000	14508.000	0.000	0.000
92.05-92.00	1	0.05	0.000	80.000	24818.000	0.000	16.000
92.00-91.95	1	0.05	0.000	160.000	43512.000	20.000	6.000
91.95-91.90	1	0.05	0.000	100.000	81424.000	0.000	16.000

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Level	Stratum	Level vol. (m^3)	Snail density (ct./m^3)	Gravel density (ct./m^3)	Rhizoconcretion density (wt. in g/m^3)	FeMn concretion density (ct./m^3)	Sandstone + caliche nodule density (g/m^3)
N113 E98							
92.72-92.50	2C	0.0897	0.000	0.000	0.000	0.000	0.000
92.50-92.40	2B	0.10	0.000	0.000	0.000	0.000	0.000
92.40-92.30	2A/2B	0.10	0.000	0.000	0.000	0.000	0.000
92.30-92.20	2A	0.10	0.000	0.000	0.000	0.000	0.000
92.20-92.15	2A	0.05	0.000	0.000	0.000	0.000	0.000
92.15-92.10	2A	0.05	0.000	0.000	0.000	0.000	0.000
Unit 2							
92.68-92.38	2B/2C	0.0950	0.000	0.000	0.000	0.000	0.000
N112 E97							
93.14-92.75	2D/3	0.2971	5250.757	2638.842	17147.089	175.025	2320.431
92.75-92.70	2C/2D	0.05	2620.000	700.000	15578.000	0.000	1902.000
92.70-92.65	2C	0.05	1880.000	600.000	16012.000	60.000	1884.000
92.65-92.60	2C	0.05	1200.000	900.000	21644.000	100.000	2554.000
92.60-92.55	2B/2C	0.05	0.000	1100.000	15186.000	120.000	3258.000
92.55-92.50	2B	0.05	260.000	1080.000	14804.000	60.000	4468.000
92.50-92.45	2B	0.05	100.000	740.000	10708.000	0.000	3582.000
92.45-92.40	2B	0.05	140.000	680.000	11866.000	100.000	2366.000
92.40-92.35	2B	0.05	0.000	480.000	4884.000	0.000	646.000
92.35-92.30	2B	0.05	120.000	1060.000	9928.000	140.000	1784.000
92.30-92.25	2A/2B	0.05	80.000	340.000	8706.000	0.000	344.000
92.25-92.20	2A	0.05	260.000	60.000	13566.000	40.000	280.000
92.20-92.15	2A	0.05	0.000	40.000	15808.000	0.000	44.000
N109 E96							
93.08-93.00	2D	0.0475	8884.211	3200.000	14048.421	63.158	5581.053
93.00-92.95	2D	0.05	5600.000	4500.000	13148.000	60.000	3154.000
92.95-92.90	2D	0.05	3760.000	2880.000	11058.000	120.000	1996.000
92.90-92.85	2D	0.05	5300.000	2480.000	13284.000	120.000	5146.000
92.85-92.80	2D	0.05	9300.000	2300.000	16214.000	80.000	16124.000
92.80-92.75	2D	0.05	6880.000	1740.000	16662.000	140.000	15210.000
92.75-92.70	2D	0.05	4200.000	2060.000	17392.000	60.000	11548.000
92.70-92.65	2D	0.05	4580.000	2200.000	15840.000	240.000	13738.000
92.65-92.60	2D	0.05	2440.000	2700.000	5588.000	200.000	13672.000
92.60-92.55	2D	0.05	1920.000	5440.000	6698.000	340.000	12442.000
92.55-92.50	2C/2D	0.05	2140.000	4940.000	7108.000	320.000	13336.000
92.50-92.45	2C	0.05	2400.000	7400.000	6200.000	320.000	17624.000
92.45-92.40	2C	0.05	1800.000	6860.000	8210.000	500.000	17442.000
92.40-92.35	2B/2C	0.05	560.000	2480.000	3616.000	180.000	7420.000
92.35-92.30	2B	0.05	320.000	1440.000	3250.000	0.000	2756.000
92.30-92.25	2B	0.05	600.000	7500.000	4808.000	400.000	19704.000
92.25-92.20	2A	0.05	100.000	19840.000	5186.000	1040.000	37794.000
92.20-92.15	2A	0.05	60.000	25700.000	13076.000	960.000	43484.000

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Level	Stratum	Level vol. (m^3)	Snail density (ct./m^3)	Gravel density (ct./m^3)	Rhizoconcre-tion density (wt. in g/m^3)	FeMn concretion density (ct./m^3)	Sandstone + caliche nodule density (g/m^3)
(N109 E96, continued)							
92.15-92.10	2A	0.05	40.000	7480.000	12280.000	580.000	24854.000
92.10-92.05	2A	0.05	160.000	15580.000	17872.000	940.000	25938.000
92.05-92.00	2A	0.05	80.000	27300.000	17524.000	700.000	32688.000

* includes a small portion of stratum 2D.

(end of data)

Appendix 5: Snails From Bulk Matrix, Selected Levels of N109 E96

Bulk matrix passing the 1/4-inch screen was collected from all levels in N109 E96 and later sieved through fine mesh, but only a few levels have been picked for bones, snails, and chipping debris. Of these, a preliminary snail inventory has been done for only three: 92.35-92.30 (stratum 2B), 92.15-92.10 and 92.05-92.00 (both stratum 2A). Note many *Cincinnatia integra* juveniles.

N109 E96, snails from bulk matrix, coarse fraction, selected levels	92.35-92.30	92.15-92.10 NE	92.15-92.10 SW	92.05-92.00 N side	92.05-92.00 remainder	ROW TOTALS
Anguispira strongylodes juveniles	100		1	7	2	110
Catinella vermeta	1	1				2
Gastrocopta contracta	153		13	1	9	176
Gastrocopta pellucida	6				1	7
Gastrocopta sp. fragments	16				2	18
Gastrocopta sp. juveniles	21					21
Glyphyalinia umbilicata	45		1	1	1	48
Hawaiia/Helicodiscus sp.	1					1
Helicodiscus singleyanus	167		3	2	15	187
Mesomphix friabilis embryos	24	1	1			26
Oligyra orbiculata adults	1	23		1		25
Oligyra orbiculata juveniles	4					4
Opercula from *Oligyra orbiculata*	49				2	51
Polygyra cf. P. *texasiana*	1					1
Polygyra sp.		4				4
Polygyra sp. juveniles	2			1		3
Praticolella sp.		1				1
Pupoides albilabris adults	5					5
Pupoides albilabris juveniles (?)	6					6
Rabdotus sp.	19	1			1	21
Strobilops texasiana adults	7		1		3	11
Strobilops texasiana juveniles	2					2
Zonitoides arboreus	7					7
Cincinnatia integra adults	13				8	21
Cincinnatia integra juveniles (?)	22		3			25
Gyraulus parvus	16			1	4	21
Helisoma anceps juveniles	4				1	5
Planorbidae	1	1		1		3
Unidentified conical			2	1	3	6
COLUMN TOTALS	693	32	25	16	52	

Appendix 6: Vertebrate Faunal Inventory

The following inventory represents vertebrate faunal remains identified to date and includes all the bone found on the ¼-inch screen and *in situ*.. It is by no means a complete inventory of animal bone from the bench deposits, however, because a substantial amount of bone has been extracted from matrix samples but not yet identified, and still more bone is known remain in matrix residue samples from N109 E96 that have not yet been picked. See Chapter 10 for counts of bone fragments not yet identified, and for explanation of identification and counting procedures.

Bones and bone fragments (numbering 3272 altogether) in this inventory are listed by lot, grouped into two major divisions, the deposit associated with Feature 5 and all the rest of the bone from the bench deposits. Individual lots list the total number of fragments, regardless of whether breakage occurred before, during, or after excavation. The two totals given for hearth-related and ambient material, however, are an estimate of the number of fragments before post-excavation damage. Hence, fragments with obvious recent breakage representing specimens which broke during cleaning are usually counted as one specimen. The summary totals given, therefore, are slightly smaller than would be obtained by adding up the lot-by-lot counts and are probably a more accurate estimate of the original number of bone fragments. This inventory is based on one compiled by Boyce Cabaniss, later amended by Alisa Winkler, Bill McClure and Ken Brown.

I. HEARTH DEPOSIT (2920 fragments)

Lot # B-105

N113 E98 (92.50-92.40)

NOTE: This lot is divided into hierarchically organized sublots representing clusters of bone excavated as chunks of matrix and later disaggregated in the lab. See the text for a discussion of these sublots and their significance.

Group 1a

Onychomys leucogaster (Northern grasshopper mouse)

right mandible: distal fragment containing root of incisor; 20%

Rana cf. *Rana berlandieri* (cf. Rio Grande leopard frog)

left humerus: distal fragment; 50%

Group 1b

Chaetodipus hispidus (hispid pocket mouse)

right mandible: fragments containing incisor

teeth: one P_4 probably from a different individual

Group 1c

Unidentified small mammal

skull roof: part of a small mammal skull roof, possibly *Scalopus aquaticus*

centrum of cervical vertebra: from small mammal; 50%

Unidentified fragments

seven unidentified bits of bone

Group 1d

Unidentified small mammal

pelvis: two fragments from a *Neotoma*-sized animal

first phalanx: one specimen from a *Neotoma*-sized animal

Group 1e

rib: shaft fragment, approximately rabbit size

Group 1f

Geomys sp. (pocket gopher)

right femur: proximal shaft fragment; 30%; comparable in size to a specimen of subadult *G. bursarius* on file at the Shuler Museum

Unidentifiable fragments

12 unidentifiable fragments, some probably from the element listed above

Group 1g

Bird, unidentified

lower beak of a small passerine bird, almost complete

Ambystoma texanum (smallmouth salamander)

vertebrae: 15 vertebrae from the same individual; some complete, others broken; two are orange, semi-glossy, the remainder beige, matte-textured; MNI =1

Rana cf. *Rana berlandieri* (Rio Grande leopard frog)

long bone shaft fragment: possible shaft of metatarsal

Fish, unidentified

vertebrae: two small vertebrae

Unidentified small mammal

caudal vertebra: one small vertebra, probably from a rodent

vertebra: lateral fragment from *Neotoma*-sized animal

Group 1h

Scalopus aquaticus (eastern mole)

right tibia: proximal fragment; 50%

left tibia: distal fragment; 25%

carpal: one complete carpal

second phalanx: one complete phalanx

skull fragments: three fragments possibly from *Scalopus aquaticus*

Chaetodipus hispidus (?) (hispid pocket mouse)

right tibia: proximal shaft fragment; 30%

Sylvilagus sp. (rabbit)

left mandible: fragment from medial side containing alveoli for P_3 and P_4; 2%

Unidentified small mammal

caudal vertebra: from a *Chaetodipus*-sized animal

rib head: from a *Neotoma*-sized animal

Unidentified fragments

three unidentified bone fragments

Group 1i

Rodent, unidentified

femur: several fragments; about the size of *Chaetodipus* (probably one fragment recently broken into three pieces)

Group 1j

Scalopus aquaticus (eastern mole)

right humerus: almost complete

Group 1k

Bird?

long bone shaft fragment: very thin-walled, probably from a small bird

Group 1 Residual Lot

Scalopus aquaticus (eastern mole)

left mandible: edentulous posterior fragment; 65%

right mandible: edentulous, otherwise almost complete, two joining fragments; 80%; possibly the same individual represented by the element listed above

left humerus: distal fragment; 30%

left humerus: proximal fragment; 70%; this and the element listed above do not join but could be from the same individual

third phalanges: two, almost complete

carpals: two carpals

left ulna: proximal fragment; 25%

left ulna: distal fragment; 40%

left tibia: two joining proximal and shaft fragments, representing 30% and 25% respectively

left tibia: distal fragment; does not join fragments listed above but may be part of same bone; 10%

teeth: one left P_4; two incisors

Geomys sp. (pocket gopher)

left femur: proximal shaft fragment; comparable to *G. bursarius*; 30%

left femur: distal exterior condyle fragment; comparable to *G. bursarius*; 5%

left femur: proximal shaft fragment (rather large; larger than comparative specimen of subadult *G. bursarius*); 30%

left humerus: distal shaft fragment; 30%

left humerus: proximal fragment; 10%

left humerus: proximal shaft fragment; 30%

right scapula: articular fragment; comparable to *G. bursarius*; 10%

teeth: left P_4; length, 2.67 mm; width 2.33 mm (somewhat smaller than a comparative specimen of female *G. bursarius* from Nebraska, with a maximum length of 3.17 mm and occlusal width of 2.50 mm)

cf. *Geomys* sp. (gopher?)

caudal vertebrae: two vertebrae from *Geomys* or similar sized rodents

right femur: exterior condyle fragment

right humerus: fragment of distal articulation; 5%

left femur: proximal shaft fragment; 20%

left femur: proximal fragment; 10%

teeth: two fragmentary incisors

Chaetodipus hispidus (hispid pocket mouse)

left mandible: edentulous anterior fragment with incisor; 40%

teeth: one upper molar, either M^1 or M^2; two unidentified molar fragments

Fish, unidentified

vertebrae: five small vertebrae (including three nearly complete centra)

unidentified elements: four unidentified fragments of fish bone

Bird, unidentified

right carpometacarpus: proximal fragment, from sparrow-sized bird; 15%

Ambystoma texanum (smallmouth salamander)

femur: one femur

humerus: three fragments (MNI =1)

vertebrae: seven vertebrae (MNI = 2)

Rana cf. *Rana berlandieri* (Rio Grande leopard frog)

left ilium: fragment including most of the acetabulum

cf. Hylidae or Microhylidae (probable; cricket, chorus, treefrogs, narrowmouth toads)

long bones: two ends of unidentified long bones (ossification indicates adults)

Frog/toad

vertebrae: three complete but mostly lacking transverse processes

femur: three ends of femur (adults; condyles are ossified)

Colubrinae

vertebrae: two vertebrae (MNI = 2)

Viperidae

Vertebrae: two vertebrae (one is caudal)

Unidentified mammal

long bone shaft fragments: 29 small fragments, probably most from mammals

long bone shaft fragment: one fragment from an animal larger than *Geomys* but probably smaller than small *Sylvilagus*

mandible fragments: five fragments of edentulous mandibles; two are of *Geomys* size, two are of *Chaetodipus* size, and the size of animal represented by the sixth cannot be estimated

vertebra fragments: six fragments (including one cervical and one caudal vertebra)

rib shaft fragments: six fragments (two large, four small)

first phalanx: two first phalanges, one *Neotoma*-sized and another very small, *Pitymys*-sized

ulna: one proximal fragment, *Chaetodipus*-sized; 50%

metapodial: seven small fragments

carpals or tarsals: two small mammal carpals or tarsals

teeth: three fragments of small rodent incisors; one insectivore incisor or premolar

Unidentified bone

unidentified fragments: 215 fragments (one of which may be potentially identifiable)

Group 2

Heteromyidae. (*Chaetodipus* or *Dipodomys*, pocket mouse or kangaroo rat)

left proximal tibia: juvenile, no epiphyses present; 30%

left mandible: one mandible fragment with incisor

Chaetodipus/Perognathus sp. (pocket mouse)

left mandible: partial mandible; 30%

Unidentified small vertebrate

unidentified bone fragments: two fragments

Group 3

Scalopus aquaticus (eastern mole)

right ulna: one specimen; 80%

Frog/toad

vertebra: centrum of trunk vertebra in two fragments; 40%

Small rodent (*Onychomys* size)

left femur: ball of femur; 5%

Fish, unidentified

vertebra: two partial centra of vertebrae from medium sized fish; one 40% and the other 5% complete

Ambystoma texanum (probable; smallmouth salamander)

vertebra: complete trunk vertebra

Amphibian, probable

unidentified limb bone end

Bird, unidentified

right ulna: proximal fragment, blue jay sized bird; 30%

Small mammal

limb bone shaft fragments: two fragments from small rodent sized animal

metapodial: proximal fragment, abraded; (*Chaetodipus*-sized animal); 60%

rib shaft fragment: one fragment (*Neotoma*-sized animal); 15%

Unidentified small vertebrate

limb bone shaft fragment: one fragment; small rodent sized animal

unidentified fragments: four fragments

Group 4

Neotoma sp. (packrat, wood rat)

right humerus: two distal fragments not joining; 45%

teeth: three lightly worn teeth (right incisor, M_1, M_2) from a large individual

Unidentified small mammal

unidentified fragments: 23 fragments, most probably from a *Neotoma* mandible represented by the teeth listed above

Group 5

Fish, unidentified

dorsal fin spine: two fragments, not joining, of the base of an anterior dorsal fin spine; medium-sized fish; 35%

[END LOT B-105]

Lot # B-106

N113 E98 (92.443-92.400)

Scalopus aquaticus (eastern mole)

left humerus: complete but in two joining fragments

left humerus: proximal fragment including head; 25%

left humerus: two joining distal fragments; 30%

left radius: complete

left radius: complete but in two joining fragments

right radius: proximal fragment; 60%

right radius: distal fragment; 15%

right ulna: fragment of proximal articular area; 10%

right ulna: fragment of proximal articular area; 15%

left femur: distal fragment; 20%

third anterior phalanges (unguals): six (one 5th left, one 5th right, four unidentified left)

second anterior phalanges: seven (three left, four right)

first anterior phalanges: six, undetermined as to side

second posterior phalanx: one

carpal/metacarpal elements: eight complete; one 60% complete

teeth: one right M^2 lightly worn; one left M_2 heavily worn; one left M_3 lightly worn; one left M_1 heavily worn; one left M^3 heavily worn; one right P^4 heavily worn; one right P^3 heavily worn; one left incisor; two incisor roots

cf. *Chaetodipus hispidus* (hispid pocket mouse)

left tibia: distal fragment; 30%

right tibia: distal fragment; 30%

teeth: one left M_1 heavily worn; one right M^2 slightly worn; one right P^4 slightly worn; one right M_2 slightly worn; one left P^4 slightly worn; one left P_4 heavily worn; one left M^1 slightly worn

Geomys cf. *G. bursarius* or *G. personatus* (pocket gopher)

metacarpals: two

teeth: one right upper molar

Sylvilagus cf. *S. audubonii* or *S. floridanus* (cottontail rabbit)

teeth: one left M_3

Dipodomys cf. *D. ordii* (Ord kangaroo rat)

teeth: one right P^4, one right M_3, one right M^2, one unidentified molar

Soricidae (shrews)

left mandible: one partial edentulous left mandible

Cryptotis parva (least shrew)

teeth: one left M_1

cf. *P. pinetorum* or *M. ochrogaster* (vole)

teeth: one right M^2

Unidentified microtine

teeth: one molar fragment

Neotoma sp. (packrat, wood rat)

right femur: shaft from young adult, missing distal epiphysis; 80%

caudal vertebrae: three

teeth: one left M^1; one left M^2; one right M^3; all from one individual

Onychomys leucogaster (Northern grasshopper mouse)

teeth: one left M^2

Peromyscus cf. *P. maniculatus* or *P. leucopus* (deer mouse or white-footed mouse)

right femur: proximal fragment

Ambystoma texanum (smallmouth salamander)

precaudal vertebrae: 18 vertebrae (14 range in length from 2.4 to 3.4 mm, mean = 2.65 mm; centra are closed)

ilium: two ilia, one burned or heat-discolored

humerus: three proximal and two distal fragments (MNI = 3)

femur: four proximal femur fragments

Ambystoma cf. *Ambystoma texanum* (cf. smallmouth salamander)

vertebrae: three charred; four manganese-stained

Ambystoma sp. (Ambystomatid salamander)

precaudal vertebrae: two vertebrae

caudal vertebrae: one vertebra (both the precaudal and caudal vertebrae are slightly larger than the *A. texanum* vertebrae listed above, hence the uncertainty about species; the centrum of one is not closed)

caudal or fragmentary vertebrae: 44 fragmentary or caudal vertebrae consistent with *Ambystoma texanum* but too incomplete for identification

long bones: seven articular ends of unidentified long bones (cf. *Ambystoma* sp.)

Salamander, unidentified

long bones: 20 fragments of unidentified long bones

vertebrae: 12 vertebra fragments

Possible salamander

axis vertebra: one vertebra, possibly from a salamander

long bone: one end of an unidentified long bone

Rana sp. cf. *Rana berlandieri* (cf. Rio Grande leopard frog)

ilium: right ilium, acetabular end, from frog with 7-8 cm snout-vent length

Bufo sp. cf. *Bufo americanus* (cf. American toad)

ilium: left ilium, acetabular end

Frog/toad

urostyle: one urostyle fragment; 25%

radio-ulna: two radio-ulna midshaft fragments

atlas vertebrae: three fragmentary atlas vertebrae (one medium, two small)

unidentified vertebrae: one vertebra fragment

Amphibian, unidentified

long bones: 12 long bone fragments of unknown amphibian

Lizard, unidentified

vertebrae: six vertebrae from a probable lizard

vertebra: one vertebra from a small lizard, perhaps subadult *Sceloporus*

Lizard, possible

unidentified fragments: four fragments from possible lizard or other small vertebrate

Snake or lizard, unidentified

vertebrae: three vertebra fragments

cf. *Rhinocheilus lecontei* (cf. longnose snake)

vertebrae: one vertebra

Colubrinae (colubrid snake, subfamily Colubrinae)

vertebrae: ten small vertebrae (four are similar to *Diadophis punctatus*, ringneck snake)

vertebrae: two vertebrae from a snake with snout-vent length about 60 cm

Natricinae (colubrid snake, subfamily Natricinae, either *Storeria dekayi* or *Virginia striatula*)

vertebrae: three vertebrae

Snake, unidentified

caudal vertebrae: five vertebrae

vertebrae fragments: four small vertebra fragments

Fish, unidentified

vertebrae: 18 vertebrae, fairly small, varying in size and completeness

dorsal fin spines: two complete specimens, very small; two basal fragments, small to medium-sized fish

pectoral fin spine: one, medium large

unidentified fin spine (?): one fragment with articular end

teeth: two

unidentified: eight bone fragments probably from fish

Bird, unidentified

long bones: six shaft fragments, all from small or very small birds

left carpometacarpus: proximal fragment, small; 15%

carpometacarpus: shaft fragment, quail-sized bird; 20%

left ulna: proximal fragment, small bird; 40%

radius: one radius fragment with articular end, very small

Unidentified rodent

left proximal femur: one fragment, juvenile individual

distal tibia: one fragment

tibia: one proximal epiphysis from juvenile, complete except for some exposure of cancellous interior

baculum: one baculum, nearly complete

Unidentified small mammal

caudal vertebrae: 23 vertebrae of various sizes, all *Neotoma*-sized or smaller

vertebrae: 11 vertebrae (one complete, remainder fragmentary)

rodent incisors: 31 incisors differing in size and completeness, none larger than *Chaetodipus hispidus*

calcanea: four, none larger than *Chaetodipus hispidus*

astragali: three, none larger than *Chaetodipus hispidus*

tarsals or carpals: 14 tarsals or carpals, all complete

first and second phalanges: 22 phalanges, none larger than *Neotoma*

third phalanges: five phalanges [one *Pitymys*-sized, two *Chaetodipus*-sized, two large (*Neotoma*-sized)]

ribs: 10 small fragments

humerus: eight fragments, none more than 50% complete, none larger than *Geomys* size

distal femoral epiphyses: three epiphyses, about *Chaetodipus* size; one epiphysis about the size of *Geomys*

proximal femoral epiphysis: one epiphysis, about the size of *Geomys*

metapodials: 25 metapodials, none larger than *Neotoma*; some complete

scapula: articular region, *Pitymys*-sized; 20%

pelvis: two fragments, one *Neotoma*-sized, the other *Pitymys*-sized; both 20% complete

femoral balls: three fragments, one epiphysis; all the size of *Chaetodipus*

proximal ulna: two fragments, the size of *Chaetodipus* or smaller; both 15% complete

radius: three fragments with articular ends

proximal radius: one fragment (juvenile)

tibia: two shaft fragments, both small, about *Pitymys* size; one 40%, the other 50% complete

unidentified charred bone: two small fragments

unidentified fragment: one unidentified manganese-stained fragment

Mammal or herpetofauna

long bones: two fragments with articular ends

Unidentified small vertebrate

probable skull fragments: 12 fragments, various sizes and thicknesses

ribs: three rib fragments

carpals or tarsals: two possible carpals or tarsals

astragalus: one complete astragalus

claw: one very small claw, complete

phalanx: one phalanx, fragmentary

Unidentified bone fragments

unidentified fragments: 1738 fragments

[END LOT B-106]

Lot # B-107A

N113 E98 (approximately upper 5 cm of 92.40-92.30 m level)

Note: this extensive lot of bone (about 1186 fragments) has not been identified yet.

Lot # B-149

Unit 2, Feature 5 (on fired surface of hearth and immediately surrounding area)

Scalopus aquaticus (eastern mole)

right humerus: 70% complete

right mandible: two joining edentulous fragments; 60%

first phalanx: proximal fragment; 30%

carpals: two carpals

Pitymys cf. *P. pinetorum* or *M. ochrogaster* (vole)

teeth: one left M_1; one left M_2

left mandible: two joining edentulous anterior fragments; 40%

Onychomys leucogaster (Northern grasshopper mouse)

teeth: left M_1; one unidentified molar fragment

Sylvilagus cf. *S. audubonii* or *S. floridanus* (cottontail rabbit)

left calcaneum: from young adult, with epiphysis unfused

Neotoma sp. (?) (packrat, wood rat?)

left scapula: articular region; 20%

Rana sp. cf. *Rana berlandieri* (cf. Rio Grande leopard frog with snout-vent length 6-7 cm)

tibiofibula: a 9 mm length of shaft midsection; 40%

ilium: right ilium, acetabular area; 15%

Unidentified mammal

rodent incisors: 3 small incisors (two lower incisors, both distal fragments, 75% and 30% complete); one distal fragment of an upper incisor, 60%

first phalanx: one phalanx, *Neotoma*-sized

right femur: proximal fragment, *Chaetodipus*-sized; 30%

right femur: three joining distal fragments, *Chaetodipus*-sized; 30%

right humerus: distal fragment, *Chaetodipus*-sized; 10%

left mandible: two fragments from diastema region; 15%

long bone shaft fragments: six fragments unidentified as to element or taxon, all no larger than *Chaetodipus* size, ranging from 5% to 60% complete

skull roof (?): one small fragment

unidentified fragments: 10 small fragments

unidentified cancellous bone: four fragments (one calcined), all from an

animal *Neotoma*-sized or larger; the calcined fragment is V-shaped in section, light gray to white on the exterior with a somewhat glossy texture, black on the interior, and is 6.1 mm long, 3.45 mm wide, with a wall thickness varying from 0.25 mm to 1.05 mm. Judging by size and thickness, it may be from a lagomorph-sized or larger animal, though not necessarily a mammal.

[END LOT B-149]

Lot # B-107

N113 E98 (92.40-92.30)

Scalopus aquaticus (eastern mole)

right humerus: 90% complete

right humerus: smaller than the other right humerus by 20%; 80% complete

right ulna: tip of olecranon process; 15%

right ulna: proximal fragment including humeral articulation; 30%

right ulna: proximal end; 15%

right femur: proximal shaft fragment; 30%

carpals (radiales?): two large carpals, one left and one right

Geomys cf. *G. bursarius* or *G. personatus* (pocket gopher)

left humerus: shaft fragment; comparable to a Recent specimen of *G. bursarius* on file at the Shuler Museum; 60%

Dipodomys cf. *D. ordii* (cf. Ord kangaroo rat)

teeth: one deciduous right P_4

Chaetodipus/Perognathus sp. (pocket mouse)

teeth: one left P_4

Neotoma sp. (packrat, wood rat)

right ischium: fragment with acetabulum; 20%

Salamander, possible

long bone: end of long bone

cf. *Bufo* sp. (probable toad)

left radius-ulna: proximal fragment; 50%

Bird, unidentified

probable distal phalanx fragment of a bird: one very small fragment

long bones: three fragments, very small

Unidentified mammal

head of humerus: probably from *Neotoma* sp. or *Geomys* sp.; 20%

first phalanges: two very small phalanges, one broken and manganese - stained

rib: shaft fragment, rabbit sized

pelvis: very small fragment, *Pitymys*-sized; 15%

incisor: one fragment, *Pitymys*-sized; 20%

long bone shaft fragments: eight fragments unidentified as to element or taxon, none larger than *Neotoma* size

Unidentified vertebrate

unidentified fragments: 118 fragments

[END LOT B-107]

II. ISOLATED BONE NOT ASSOCIATED WITH FEATURE 5 (351 fragments)

Items listed below were either plotted and recovered *in situ*, found on the ¼-inch screen, or recovered from sediment samples processed for microsnails and sediment analysis. Bones from sediment samples generally come from the lower two-thirds of an arbitrary excavation level (see Chapter 3 on excavation methods).

Lot #B-104

N113 E98 (92.722-92.500)

Fish, unidentified

vertebra: half of a small vertebra

Unidentified animal

Unidentified fragment: one fragment

Lot # B-108

N113 E98 (92.20-92.15)

Geomys sp. (pocket gopher)

right mandible with teeth: badly fragmented, but includes complete tooth row and incisor; comparable in size to a Recent specimen of *G. bursarius*

Unidentified mammal

third phalanx: from an unidentified rabbit-sized animal

Lot B-108: Plotted bone at N113.64 E98.86 (elevation 92.14 m)

Unidentified animal

long bone shaft fragment: from a raccoon-sized or larger animal; with

dry bone fracture, very slight polish, yellow stain

NOTE: As in the case of lot B-105, this lot mostly consists of sublots representing small chunks of matrix collected intact in the field and later dissolved in the lab.

Group 1

Unidentified small mammal

distal epiphysis of femur: from a *Neotoma*-sized animal

unidentified fragments of cancellous bone: 11 fragments, probably from one element

Group 2

Unidentified small mammal

long bone shaft fragments: six fragments representing one or more animals the size of *Neotoma* or smaller

unidentifiable bone fragments: about 24 fragments

Group 3

Unidentified small mammal

long bone (probably humerus) shaft fragments: 17 fragments (probably representing one element) from a *Neotoma*-sized animal

Group 4

Unidentified small mammal

vertebra (?) fragments: 44 mostly very small fragments, possibly from a *Neotoma*-sized animal

Group 5

cf. Leporidae (rabbit?)

metapodial: one distal fragment probably from a large rabbit (?), perhaps

Sylvilagus aquaticus or *Lepus californicus* (?); 30% complete, badly fragmented

Group 6

Cricetidae (cricetid rodent; i.e., harvest, deer, grasshopper mice, etc., cotton rat, packrat, vole, etc.)

left femur: proximal shaft fragment, comparable in size to *Chaetodipus hispidus*; 40%

Unidentified animal

unidentified fragments: 32 very small fragments, possibly from the femur listed above

Lot # B-109

N113 E98 (92.15-92.10)

Unidentified animal

centrum of vertebra: in two fragments, from rabbit -sized or larger animal

unidentified fragment: possibly a zygapophysis from another vertebra

unidentified fragments: 49 small fragments, possibly from a small rabbit-sized vertebra

long bone fragments: unidentified fragments, probably all from one element disintegrated during cleaning

phalanges?: three very small fragments, possibly phalanges of an unidentified small vertebrate

Lot #B-110

N113 E98 (92.30-92.20)

Geomys sp. (pocket gopher)

teeth: one right I^1; width of this specimen is 2.67 mm, as compared to a width of 3.17 mm for a Recent specimen of *G. bursarius* from Nebraska on file at the Shuler Museum

Lot # B-150

Unit 2: Isolated bone found directly under Feature 5 (Note: although this single specimen was found about 10 cm directly under the hearth when it was removed from the site, it appears to predate development of the fired surface and is presumed to be unrelated). The field notes list two bones, but only one is inventoried here.

Sylvilagus sp. (cottontail rabbit)

femur: distal femur, disintegrated during collection

Lot # B-1

N109 E103 (93.14-92.90)

Geomys sp. (pocket gopher)

left mandible: anterior fragment with P_4; 50%

Lizard, probable

vertebra: one fragment of a small vertebra probably from a lizard

Unidentified animal

long bone shaft fragments: two calcined fragments from a deer-sized animal; some polishing on interior of one

unidentified fragments: fragments in carbonate concretion

Lot # B-2

N109 E103 (93.14-92.90) from sediment sample

Geomys sp. (pocket gopher)

maxilla: anterior fragment with left and right P^4

teeth: isolated upper molar probably from the maxilla listed above

cf. *Pitymys pinetorum* or *Microtus ochrogaster* (vole)

teeth: left M^3

Cryptotis parva (least shrew)

right mandible: posterior edentulous fragment; 30%

Chaetodipus hispidus (hispid pocket mouse)

left femur: anterior shaft fragment

cf. *Ambystoma* sp. (cf. Ambystomatid salamander)

vertebra: one fairly large complete vertebra

Unidentified rodent

calcaneum: from *Chaetodipus*-sized animal

Unidentified animal

long bone or rib shaft fragments: two, very small

long bone shaft fragments: two, from a rabbit-sized (?) animal; both have probable gastric rounding and polish over green bone fractures

rib fragment: anterior fragment from small rib

femur shaft fragment: from a *Chaetodipus*-sized animal

unidentified fragments: two cancellous bone, one dense bone fragment

Lot # B-3

N109 E103 (92.90-92.85)

Geomys sp. (pocket gopher)

right mandible: with I, P_4, M_2, M_3

left mandible: in carbonate concretion with P_4 and M_1 visible

Bird?

humerus: proximal fragment from a small bird (?)

Sylvilagus sp. (cottontail rabbit)

right calcaneum: distal fragment from a small rabbit; 50%

Unidentified rodent

tibia: distal fragment

long bones: two internal casts with adhering bone, both from *Chaetodipus* -sized animal

Unidentified small vertebrate

long bone shaft fragments: eight small fragments, from small vertebrate, many probably from mammal

rib shaft: one fragment

Unidentified animal

unidentified fragment: cancellous bone probably from rabbit-sized or larger animal; calcined

unidentified fragments: two (one in carbonate concretion)

Lot # B-4

N109 E103 (92.90-92.85) from sediment sample

Fish, unidentified

spine fragments: six (two from medium sized fish; four from medium-sized fish)

Frog/toad

Urostyle (?): one proximal fragment

Unidentified animals

caudal vertebra: from a *Neotoma*-sized animal; 50%

teeth: enamel fragment, possibly from a *Neotoma* molar

long bone or rib shaft fragments: four small fragments

unidentified fragments: three fragments

Lot # B-5

N109 E103 (92.85-92.80)

Sylvilagus cf. *S. audubonii* or *S. floridanus* (cottontail rabbit)

right mandible: fragment with M_3-P_3

right astragalus: mostly complete

Sylvilagus? sp. (cottontail rabbit?)

vertebra: one fragment probably from *Sylvilagus*

Sylvilagus sp. or bird

long bone shaft fragment: badly fragmented remains of shaft

Geomys sp. (pocket gopher)

left mandible: fragment with M_1, P_{4P}, and I; for the P_4, occlusal length is 3.83 mm, width is 1.83 mm

humerus: shaft fragment probably from *Geomys* sp.

Unidentified rodent

femur: small rodent femur shaft fragment

Unidentified animal

unidentified bone fragment

Lot # B-6

N109 E103 (92.85-92.80) from sediment sample

Fish, unidentified

unidentified fragment: one fragment of probable fish bone

Lot #B-7

N109 E103 (92.80-92.75)

Sylvilagus sp. (cottontail rabbit)

right scapula: fragment of neck near articulation, 14.6 mm long

Rabbit or bird

long bone shaft fragment: internal cast with adhering bone fragments

Possible herpetofauna?

humerus: fragment embedded in concretion

Unidentified animal

scapula: one fragment from a *Geomys*-sized animal

humerus?: fragment embedded in concretion

unidentified fragment: small fragment of cancellous bone

Lot # B-8

N109 E103 (92.75-92.70)

Sylvilagus sp. (cottontail rabbit)

left ilium: distal fragment including part of acetabulum, 12 mm long,

from a small rabbit

right tibia: proximal fragment

Lot # B-9

N109 E103 (92.75-92.70) from sediment sample

Unidentified rodent

right proximal femur: shaft fragment from *Chaetodipus*-sized rodent, stained dark reddish brown

Unidentified animal

long bone: internal cast with adhering bits of bone from a rabbit-sized animal (probably rabbit or bird)

unidentified fragment: flat bone fragment, possibly pelvis fragment from a small mammal

Lot # B-11

N109 E103 (92.65-92.60)

Sigmodon hispidus (hispid cotton rat)

teeth: left M_3 and M_2 with bits of mandible embedded in carbonate concretion

Rabbit or bird

long bone shaft fragments: two internal casts with adhering bone, probably from *Sylvilagus* sp. or a bird of comparable size

Lot # B-16

N109 E103 (92.55-92.50) from sediment sample

Bird?

long bone shaft fragment: thin walled, from a bird or rabbit

Lot # B-17

N109 E103 (92.50-92.45)

Geomys sp. (pocket gopher)

teeth: maxillary dentition with right M^2 and left M^2, M^3 embedded in carbonate concretion

Unidentified rodents

incisor: internal cast of large rodent incisor

incisor: small fragment of *Pitymys*-sized rodent incisor

Lot # B-18

N109 E103 (92.45-92.40)

Unidentifiable animal

unidentifiable fragments: many fragments, probably of one bone

Lot # B-19

N109 E103 (92.45-92.40) from sediment sample

cf. *Rana berlandieri* (cf. Rio Grande leopard frog)

urostyle: articulating end of urostyle from a small frog

Lot # B-28

N109 E103 (92.10-92.05) from sediment sample

Bird, unidentified

left coracoid: anterior (proximal) fragment, from pigeon-sized bird; 30%

Lot # B-29

N109 E103 (92.05-92.00)

Bird?

long bone: end of unidentified long bone, probably from a small bird

Unidentified animal

long bone shaft fragment: small fragment from a deer-sized animal

Lot # B-31

N109 E103 (92.00-91.95)

Unidentified animals

long bone shaft fragments: two fragments probably from the same bone, though not joining; from a deer-sized animal. One is large (4.7 x 1.0 cm, spirally fractured), the other smaller (1.8 x 1.0 cm)

rib shaft: fragment from a *Geomys*-sized animal

unidentified fragments: two small fragments

Lot # B-32

N109 E103 (91.95-91.90)

Unidentified animal

long bone shaft fragments: three fragments, the largest about 9 mm long, from *Neotoma*- or *Geomys*-sized animals

Lot # B-33

N110 E102 (93.08-92.90)

Unidentified mammal

long bone shaft fragment: one spirally fractured fragment probably from humerus or femur of deer-sized animal

unidentified fragment: one flat piece of bone with possible gastric rounding, probably from a deer-sized animal

long bone shaft fragment: from a *Chaetodipus*-sized animal

Lot # B-34

N110 E102 (92.90-92.80)

Unidentified animal

unidentified fragments: adhering to carbonate concretion

long bone shaft fragment: internal cast with some adhering bone fragments, possibly from a medium-sized bird or rabbit

rodent incisor: fragment from *Pitymys*-sized animal

Lot # B-35

N110 E102 (92.90-92.80) from sediment sample

Unidentified animal

long bone shaft fragment: from rabbit sized animal

Lot # B-36

N110 E102 (92.80-92.75)

Geomys sp. (pocket gopher)

right mandible: embedded in carbonate concretion; incisor is only tooth visible

Lot # B-40

N110 E102 (92.60-92.55

Procyon lotor? (raccoon?)

teeth: fragment of right M_1 in carbonate concretion

Lot # B-43

N110 E102 (92.50-92.45)

Geomys cf. *G. bursarius* or *G. personatus* (pocket gopher)

left mandible with teeth: in carbonate concretion, fractured by carbonate growth

Lot # B-44

N110 E102 (92.50-92.45)

Fish?

unidentified bone fragment: one fragment

Unidentified animal

unidentified fragment: one fragment

Lot # B-45

N110 E102 (92.45-92.40)

Geomys sp. (pocket gopher)

right mandible: fragment with P_4, M_1, and M_2

Lot # B-46

N110 E102 (92.45-92.40) from sediment sample

Virginia striatula (Rough earth snake)

vertebra: one small vertebra

Unidentified animal

unidentified fragments: two fragments

Lot # B-50

N110 E102 (92.30-92.25)

Unidentified animal

long bone shaft fragment: internal cast probably from rabbit or bird

unidentified fragments: in carbonate concretion; probably rabbit or bird

Lot # B-51

N110 E102 (92.30-92.25) from sediment sample

cf. *Ambystoma* sp. (cf. Ambystomatid salamander)

vertebra: half of the centrum of a small vertebra

Unidentified animal

unidentified fragment: one fragment

Lot # B-52

N110 E102 (92.25-92.20)

Sylvilagus sp. (cottontail rabbit)

tibia: internal cast, with adhering bone bits, of distal end of tibia, lacking the epiphysis, from a small rabbit

Unidentified animal

unidentified fragments: fragments of one bone, possibly edentulous mandible of a small rodent (?)

Lot # B-54

N110 E102 (92.20-92.15)

Unidentified animal

antler fragments: seven small splinters of charred antler, probably one fragment shattered during excavation

Lot # B-57

N110 E102 (92.10-92.05)

Unidentified animals

long bone shaft fragments: two internal casts of long bones from rabbit -sized animal, with bone fragments adhering

antler or long bone shaft fragment: one fragment from a deer-sized animal; burned

Sylvilagus sp. (cottontail rabbit)

right calcaneum: proximal fragment from a small rabbit

Lot #B-59

N110 E102 (92.05-92.00) from sediment sample

Fish, unidentified

teeth: one fairly large tooth

Unidentified small mammal

patella: one patella

long bone shaft fragments: six small, from *Chaetodipus*-sized animal

Unidentified animal

unidentified fragments: four unidentified fragments

Lot #B-61

N110 E102 (92.00-91.95) from sediment sample

Onychomys leucogaster (Northern grasshopper mouse)

teeth: one right M_1

Geomys sp. (pocket gopher)

teeth: unidentified molar

Unidentified rodent (?)

long bone shaft fragments (?): two unidentified fragments, probably rodent long bone fragments

Lot # B-62

N110 E102 (91.95-91.90) from sediment sample

Geomys sp. (pocket gopher)

teeth: unidentified molar (M1 or M2; whether mandibular or maxillary dentition cannot be identified)

Lot # B-62A

N110 E102 (91.95-91.90)

Unidentified animal

long bone shaft fragment: small fragment from a *Geomys*-sized animal;

burned

Lot # B-63

N110 E102 (91.90-91.85)

Sylvilagus sp. (cottontail rabbit)

right astragalus: nearly complete astragalus from a small rabbit; 80%

Unidentified animal

femur (?): shaft fragment from a *Geomys*-sized animal

Lot # B-69

N110 E102 (91.70-91.65)

Unidentified animal

antler (?) fragment: small sliver of charred antler or bone

Lot # B-72

N111 E101 (92.80-92.70)

Unidentified small vertebrate

long bone shaft fragment: one fragment

Unidentified animal

unidentified fragments: two fragments

Lot # B-73

N111 E101 (92.70-92.65)

Unidentified animal

long bone: fragment embedded in carbonate concretion, from a rabbit or

bird

Lot # B-76

N111 E101 (92.55-92.50)

Unidentified animal

long bone: fragment embedded in carbonate concretion, from a rabbit or bird

Lot # B-86

N111 E101 (92.05-92.00)

Unidentified animal

unidentified fragments: four cancellous bone fragments apparently from the same bone

Lot # B-88A

N111 E101 (91.95-91.90)

Unidentified animal

pelvis (?) fragment: one calcined fragment from a *Geomys*-sized animal

Lot # B-89

N112 E99 (92.89-92.60)

Unidentified small vertebrate

vertebra: one small dorsal fragment from snake, lizard, or small mammal; stained or oxidized reddish brown

Lot # B-91

N112 E99 (92.55-92.50)

Unidentified animal

femur: distal epiphysis (?) and possible shaft fragments of a rabbit sized animal (?)

Lot # B-92

N112 E99 (92.50-92.45)

Bird, unidentified

left femur: proximal fragment of a small bird; 20%

Unidentified animal

unidentified fragment: one fragment

Lot # B-98

N112 E99 (92.20-92.15)

Geomys sp. (pocket gopher)

teeth: two fragments of lower incisor (?), probably from *Geomys* sp.

Lot # B-101

N112 E99 (92.05-92.00)

Unidentified animal

vertebra: two fragments, possibly of a small vertebra

unidentified fragments: two small fragments, possibly of a small vertebra

Lot # B-109

N113 E98 (92.15-92.10)

Unidentified animal

phalanx?: three fragments resembling phalanx of unidentified small vertebrate

Lot # B-111

N112 E97 (93.14-92.75) bag 1 of 2

cf. *Ambystoma* sp. (cf. Ambystomatid salamander)

vertebrae: one large vertebra and a smaller vertebra fragment

Unidentified animal

unidentified fragments: two fragments

Lot # B-116

N112 E97 (92.60-92.55)

Unidentified rodent

metapodial: distal epiphysis from *Geomys*-sized rodent metapodial

Unidentified animal

unidentified fragments: three small fragments

Lot # B-123

N112 E97 (92.25-92.20)

Unidentified rodent

long bone shaft fragment: one fragment from medium-sized rodent

Unidentified animal

caudal vertebra: centrum of caudal vertebra (epiphyses unfused) from raccoon-sized animal

Lot # B-125

N109 E96 (93.08-93.00)

cf. *Ambystoma* sp. (cf. Ambystomatid salamander)

vertebra: half of a vertebra

Lot # B-126

N109 E96 (92.95-92.90)

Unidentified small mammal

vertebra: one vertebra

Unidentified animal

unidentified fragment: one fragment, possibly a rib shaft fragment from a small vertebrate

Lot # B-128

N109 E96 (92.85-92.80)

Turtle, unidentified

carapace: one turtle carapace fragment, 7.5 mm long, 4.0 mm wide, maximum thickness 1.9 mm; no sutures evident

Lot # B-129

N109 E96 (92.80-92.75)

Fish, unidentified

left mandible: from a small unidentified fish

Snake, unidentified

vertebra: anterior portion of centrum from a small vertebra

Unidentified animal

long bone shaft fragment: two small shaft fragments

Lot # B-130

N109 E96 (92.75-92.70)

Unidentified animal

long bone shaft fragment: very small, from small rodent or insectivore -sized animal

unidentified fragment: one very small fragment of cancellous bone, possibly the end of the centrum of a mammal vertebra

Lot # B-131

N109 E96 (92.70-92.65)

Sylvilagus sp. (cottontail rabbit)

teeth: one fragment of lower cheek tooth

cf. *Ambystoma* sp. (cf. Ambystomatid salamander)

vertebra: one vertebra

Nerodia sp.

vertebra: one large vertebra

Unidentified rodent

long bone shaft fragment: one fragment from *Chaetodipus*-sized rodent

Unidentified animal

unidentified fragments: five fragments, one pitted

Lot # B-133

N109 E96 (92.60-92.55)

Scalopus aquaticus (eastern mole)

left humerus: distal fragment; 30%, iron oxide stained

Unidentified rodents

vertebrae: three fragments, the largest a nearly complete lumbar vertebra, possibly from *Geomys* sp.

Unidentified animal

long bone fragments: three very small fragments, one blackened by charring or manganese staining, one from very small animal

unidentified fragments: eight small fragments, some possibly of vertebrae, one possibly femoral head or part of axis vertebra from a small mammal

Lot # B-134

N109 E96 (92.55-92.50)

Kinosternidae, cf. *Sternotherus odoratus* (unidentified mud or musk turtle)

carapace: two joining fragments of right pleural plate; when rejoined, 14.1 mm long, 9.15 mm wide, thickness range 0.9-1.7 mm. Probably *Sternotherus odoratus* (stinkpot turtle), but possibly a subadult *Kinosternon* sp. (mud turtle). Plate is arched, from near the medial ridge and has small conical pits as part of the exterior surface sculpturing.

Lot # B-135

N109 E96 (92.50-92.45)

Rana catesbeiana (bullfrog)

urostyle: anterior articular surface of urostyle from a very large frog, probably a bullfrog

Salamander

vertebra: one fragment

Unidentified animals

caudal vertebra: from a mammal, probably a *Neotoma*-sized rodent

unidentified fragment: one fragment

Lot # B-136

N109 E96 (92.45-92.40)

Sylvilagus cf. *S. audubonii* or *S. floridanus* (cottontail rabbit)

tibia: two proximal fragments of a tibia, calcined and thermally fissured and warped (possibly from some other rabbit sized animal)

Unidentified rodent

rib: one shaft fragment of a small rodent rib

cf. *Rana berlandieri*

pelvic girdle: one small eroded fragment from a medium sized frog

Fish, unidentified

teeth: one very small fish tooth

Unidentified animal

skull fragment(?): one thin fragment with parallel cut marks (definite example of modification by a stone tool)

unidentified fragments: three small fragments

Lot # B-137

N109 E96 (92.40-92.35)

Salamander

vertebra: part of one vertebra in two fragments

Unidentified small mammal

vertebra: anterior end of axis vertebra

Unidentified animals

long bone shaft fragment: one small fragment (4.2 mm long), charred or stained by manganese, with probable gastric polish on interior surface

unidentified fragment: two fragments (one may be part of salamander vertebra listed above)

Lot # B-139

N109 E96 (92.35-92.30) bag 2 of 2

Dipodomys sp. (unspecified kangaroo rat)

left tibia: left proximal tibia fragment; 15%

Kinosternidae (unidentified mud or musk turtle)

carapace: one fragment of peripheral plate 9.5 mm long, 5.9 mm wide, thickness range 1.1-1.95 mm; flat tapering fragment with cavity for rib insertion on thin edge

Lot # B-140

N109 E96 FEATURE 7 FILL (92.35-92.30)

cf. *Dipodomys ordii* (Ord kangaroo rat)

left tibia: shaft and part of distal end with unfused epiphysis, probably from *D. ordii* juvenile; 40%

cf. *Rana berlandieri* (cf. Rio Grande leopard frog)

tibiofibula: end of tibiofibula

Unidentified animal

skull fragment (?): badly shattered, possibly skull of a small mammal (*Scalopus aquaticus?*)

Lot # B-141

N109 E96 (92.30-92.25)

Unidentified animal

long bone shaft fragment: from an animal larger than a rabbit, probably deer- or wolf-sized

unidentified fragments: three fragments

Unidentified small mammal

Tibia (?): proximal shaft fragment of probable tibia from a very small mammal

Lot # B-141A

N109 E96 FEATURE 7 FILL (92.30-92.25)

Unidentified small mammal

left tibia: shaft fragment from *Chaetodipus*-sized small mammal

Lot # B-142

N109 E96 (92.25-92.20)

cf. *Gopherus hexagonatus* (large extinct tortoise)

carapace fragment: one small tabular fragment of plastron or carapace (has finely textured surface on exterior side, large-celled cancellous interior bone exposed on other side)

Lot # B-143

N109 E96 (92.25-92.20)

Turtle, unidentified (perhaps Kinosternidae, mud or musk turtle)

carapace: two fragments do not join but are evidently pieces of one fragment broken during excavation; both appear slightly heat-discolored; larger fragment (6.3 mm long, 6.0 mm wide, thickness 1.2-1.3 mm) has part of a suture along one edge; smaller fragment is 5.35 mm long, 4.8 mm wide, 0.9-1.35 mm thick Small variety of turtle, perhaps Kinosternidae

Lot # B-144

N109 E96 (92.20-92.15)

Geomys sp. (pocket gopher)

teeth: one M_3

Unidentified small mammal

long bone shaft fragment: one small fragment

Unidentified animal

unidentified fragment: one fragment

Lot # B-146

N109 E96 SW half (92.15-92.10)

Turtle, unidentified (perhaps Emydidae, map, cooter, slider turtles)

carapace: one small fragment, type indeterminate; 6.0 mm long, 5.9 mm wide, thickness range 2.0-2.25 mm. Medium-sized turtle, perhaps Emydidae

Lot # B-147

N109 E96 (92.10-92.05)

Neotoma sp. (packrat, wood rat)

teeth: one unidentified molar fragment

Lot # B-148

N109 E96 (92.05-92.00)

Unidentified animal

unidentified fragments: two fragments

Lot #B-154

Cutbank profile, Stratum 1 (elevation approximately 92.12 and 92.08 m)

Emydidae (*Pseudemys concinna* or *Trachemys scripta*, river cooter or red-eared slider)

plastron: one large hypoplastron fragment (7.8 x 3.2 cm, maximum thickness 5.94 mm, with two exterior sulci); one smaller fragment, apparently of anterior margin of epiplastron (4.0 x 3.3 cm; maximum thickness 6.14 mm, curvilinear sulci on interior and

exterior surfaces), plus six small tabular fragments, one of which has two parallel cut marks on the interior (?) surface. All were found closely associated and apparently are fragments of the same plastron, comparable in shape and size to mature red-ear turtle. See discussion in chapter 10; see Figs. 3.1, 4.22, and 4.54.

Lot # B-156

Cutbank profile, Stratum 2C (elevation 92.46 m; see profile for location)

Procyon lotor (raccoon)

left distal humerus: one left distal humerus, about 60% complete, with part of articular end removed by trowel; proximal end appears to have spiral fracture. Oblique cutmark on anterior surface (9 mm long and 0.3 to 0.6 mm wide, V-shaped in cross-section) is located 1.5 cm from distal end and is tentatively regarded as a butchering mark made with a stone tool; appearance is different from marks left elsewhere on surface during cleaning with a dental pick; however, dirt and PVA obscure the scar.

PARTIALLY IDENTIFIED LOTS FROM N109 E96

Three lots of bone extracted from the coarse fraction of wet-sieved bulk matrix sample from N109 E96 (passing the ¼-inch screen) were sent to Bill McClure for identification in 1989. These include both herpetofauna and non herpetofauna and are listed below; completeness estimates were not done. Other lots of bone have been picked but not yet identified, while still other samples have not yet been picked.

Lot # B-157

N109 E96 (92.50-92.45) bulk soil sample

cf. *Lepus californicus* (cf. black-tailed jackrabbit)

scapula: fragment of border of glenoid fossa from right scapula, calcined

Sylvilagus sp. (cottontail rabbit)

metatarsal: distal end of metatarsal

Chaetodipus hispidus (hispid pocket mouse)

incisor: right upper incisor

cf. *P. pinetorum* or *M. ochrogaster* (voles)

femur: proximal half of right femur

metatarsal: one metatarsal

Frog/toad, small, unidentified

tibiofibula: midshaft of tibiofibula

Unidentified vertebrate

Unidentified fragments: 40 fragments

Lot # B-158

N109 E96 (92.70-92.65) bulk soil sample

cf. *Geomys* sp. (cf. pocket gopher)

cheek tooth: unidentified cheek tooth, subadult

incisor: upper incisor, subadult

cf. *Bufo* sp. (unidentified toad)

humerus: proximal end of humerus

Snake, unidentified

vertebra: small vertebra from unidentified snake

Unidentified vertebrate

Unidentified fragments: 31 fragments

Lot # B-159

N109 E96 (92.35-92.30) bulk soil sample

Geomys sp. (pocket gopher)

incisor: one lower incisor

cf. *P. pinetorum* or *M. ochrogaster* (voles)

cheek tooth: fragment of unidentified cheek tooth

Rana cf. *Rana berlandieri* (cf. Rio Grande leopard frog)

ilium: left ilium

phalanges: two phalanges

cf. *Bufo* sp. (unidentified toad)

humerus: proximal end of humerus

Small mammal, unidentified

humerus: midsection from humerus of a *Sigmodon*-sized mammal

Unidentified vertebrate

unidentified fragments: 37 unidentified fragments

END OF FAUNAL INVENTORY

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Vita

Kenneth Martin Brown was born in Austin, Texas, the son of Howard E. and Nina F. Brown. After service in the US Army (1966-68), he received a BA degree from the University of Texas at Austin and an MA from Northwestern University. He was a crew member at Berger Bluff during the blufftop excavations in the summer of 1979, returned to the site in the fall of the same year as field director for testing of the bench deposits, and returned again in 1983 for backhoe testing and survey of the Flume No. 3 route at Coleto Creek Reservoir.

Permanent address: 3504 Balcones Drive
Austin, Texas 78731

This dissertation was typed by the author.